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# Parasite Species Richness of fish from Lake Baringo, Kenya

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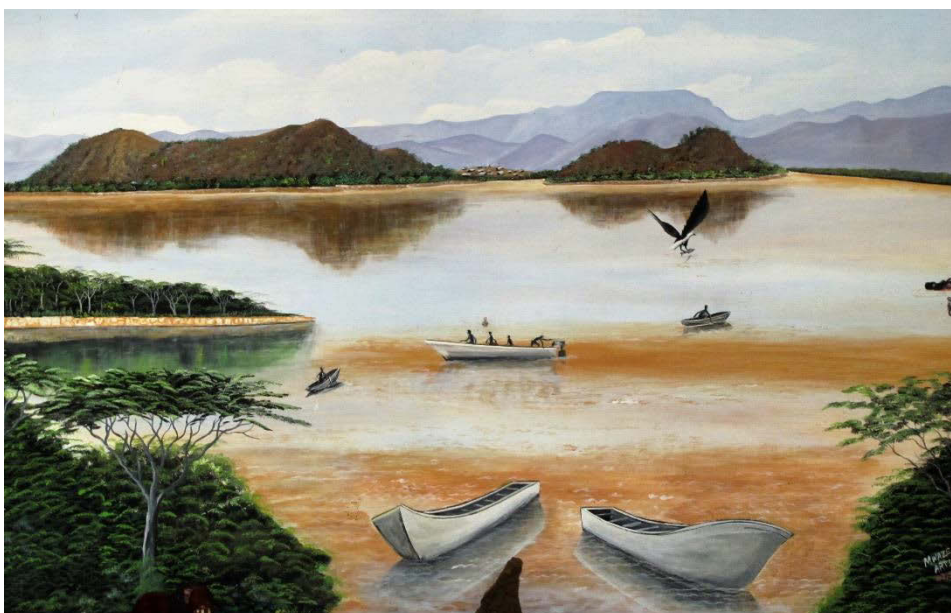
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## Abstract

A fish parasitological survey was carried out at Lake Baringo, Kenya from March to April 2015 to study the presence of endoparasites of four fish species. A total of 101 specimens of *Oreochromis niloticus baringoensis*, *Protopterus aethiopicus*, *Barbus intermedius australis* and *Clarias gariepinus* were examined using conventional parasitological techniques. The focus of this study was on the intestinal helminths of the systematic groups digenean trematodes, cestodes, nematodes and acanthocephalans. In addition to epidemiological parameters, as prevalence, mean intensity and abundance, parasite biodiversity was calculated. The endoparasite fauna was dominated by larval cestodes, metacercariae of digenean trematodes and larval nematodes. Digenean metacercariae of the genus *Clinostomum* sp. and larval nematodes of the genus *Contraecum* sp. and *Eustrongylides* sp. were recorded, potentially representing a risk to human health. Finally, we looked at parasitic life cycles and their hosts' habitat and diet composition, and findings were compared with parasitic data available from other lakes in East Africa.

Keywords: Fish diseases, *Oreochromis niloticus baringoensis*, *Barbus intermedius australis*, *Clarias gariepinus*, *Protopterus aethiopicus*, Parasites, Helminths, Lake Baringo, Kenya



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## 1 Introduction

As fish are one of the most important protein sources worldwide, there has been a strong increase in the world's demand for fish (FAO, 2016c; Hoffman, 1967). Aquaculture is growing rapidly, especially in Kenya (FAO, 2016c). The intensification of fish production in these artificial systems is increasingly leading to disease and parasitic mass infections (Dogiel et al., 1961). More than 80% of all diseases affecting warm water fish are triggered by parasitism (El-Seify et al., 2011). While the presence of parasites can be considered normal in healthy and functioning ecosystems, the numbers in which parasites are occurring in aquaculture are much larger than normal and this has been leading to serious problems (Dogiel et al., 1961). In fish farms, the overcrowded fish populations enable parasites to be more successful in spreading their hosts. This means that parasites transmit and reproduce faster in aquaculture than they do in natural conditions, often leading to high economic losses from high mortality rates, organ and tissue damage, and strong declines in reproduction success (Hoffman, 1967; Reichenbach-Klinke, 1975). Thus, parasites are causing limitations and high economic losses in fish farms, as well as in the fishing industries of free water bodies (Barber et al., 2000). In natural conditions parasites normally live in a complex equilibrium with their hosts, with diseases and parasitism existing at normal levels in well-functioning ecosystems. However, parasite infections may also have a strong impact on a fish's fitness factor and its lifetime too (Barber et al., 2000). Parasites are capable of reducing host fitness, inducing a wide variety of behavioral changes in their hosts, such as swimming fitness, habitat selection, sexual behavior, reproduction success, predator-prey relationships and food competition (Poulin, 2006).

As parasites, especially endoparasites, have very complex life cycles and are strongly influenced by fluctuations in the food chain/trophic system, understanding the host ecology of parasites helps us gain information about trophic levels, interaction-relationships and healthiness in aquatic ecosystems. Therefore, parasites can be used as biological indicators for environmental stress in ecosystems (Hudson et al., 2006, Madanire-Moyo & Barson, 2010). A disrupted ecosystem may lead to different outcomes of parasitological infections: It can potentially increase host vulnerability to parasite infection and support the appearance of epizootic parasite species for a short time (Hoffman, 1967; Aloo, 2002). In contrast, environmental stress has been associated with depression in parasite community richness (Madanire-Moyo & Barson,

2010). Upon research of literature, it is obvious that the ecosystem of Lake Baringo is undergoing significant environmental changes. Abiotic parameters are simultaneously changing and deforming the lake's species composition and organism interactions (Omondi et al., 2014). For this study, parasites cannot be used as indicators because other studies on the parasitic fauna of Lake Baringo are missing and no comparison can be made to assess changes in species composition in response to ecosystem alterations (Madanire-Moyo & Barson, 2010). There is only data from two studies on two species of fish parasites in Lake Baringo available (Britton et al. 2009; Paperna, 1996). Instead, a comparison with available parasite data from other lakes in Kenya and East Africa was carried out.

While there is plenty of information available on the ecology and life cycles of freshwater fish parasites in Europe, Russia and the United States of America (Aloo, 2002), in Eastern Africa, research in this field of biology is not yet well established (Aloo, 2002). For example, there are currently no scientific papers regarding the possible parasite infections of the northern lungfish *Protopterus aethiopicus* available, representing a serious deficiency in parasitic scientific research. More than that, according to Florio et al. (2009), Reichenbach-Klinke (1975) and Hoffman (1967), there exists a public health risk because some parasites, often found in tropical fish, also affect humans. Especially in the rural areas, where raw and smoked fish are commonly eaten, there is a high risk for accidental human infections. Information gained about species composition and biological behavior of parasites would help develop monitoring systems to control and prevent fish diseases, control parasites and minimize health risks for human beings.

## 2 Research aims

The purpose of this research is to record and identify the parasite populations of fish from Lake Baringo, to provide data for parasite species richness and diversity calculations and to compare the composition and distribution of the fish parasite community with the existing parasite data of other lakes in East Africa (Kenya, Ethiopia, Tanzania and Uganda).

### 2.1 Research questions

- What are the common ecto- and endoparasites of fish in Lake Baringo?
- Does species composition differ among the different lakes in Kenya, Ethiopia, Tanzania and Uganda?
- Are there parasites, which might be harmful for humans?

### 2.2 Hypothesis

- Fish of Lake Baringo are not infected with parasites
- There is no difference in the prevalence, mean intensity, abundance and species composition of parasites in the four fish species *Oreochromis niloticus baringoensis*, *Barbus intermedius australis*, *Clarias gariepinus* and *Protopterus aethiopicus*

### 3 Material and methods

In this chapter, characteristics of Lake Baringo, as well as the methods are described in detail in that order: study area, fish fauna, fishery and methods. Additionally, ecological and statistical definitions and the subsequent use is explained in the parts terminology and analyses.

#### 3.1 Study area

The research was carried out between March and April 2015 in Lake Baringo, a freshwater lake in the Eastern part of the Rift Valley in District Baringo, as depicted in figure 1 and 2 (Kembenya et al., 2014). The exact geographical coordinates are latitude  $0^{\circ} 30' 0''$  North,  $0^{\circ} 45' 0''$  and longitude  $36^{\circ} 10'$  East, 60 kilometers from the equator. The surface area of the lake is approximately  $130 \text{ km}^2$  at an altitude of 975 m above sea level and a catchment area size of  $6,820 \text{ km}^2$ . The lake's basin is bordered on the West by the Tugen Hills, on the South by the Eldama Ravine and on the East by the Laikipia Plateau (IW:LEARN, 2005). Ol Arabel, Mukutan, Endaoo are seasonally occurring rivers, and Molo as permanent river feed into Lake Baringo. Most rivers feeding into Lake Baringo are already dammed and any incoming water flow controlled (Omondi et al., 2011). Some of these river systems are sources of polluted agricultural substances, resulting in a rising number of nutrients in the lake systems. Furthermore, as Lake Baringo does not have an identified outlet, the accumulation of polluted substances within its system is inevitable (Omondi et al., 2014).

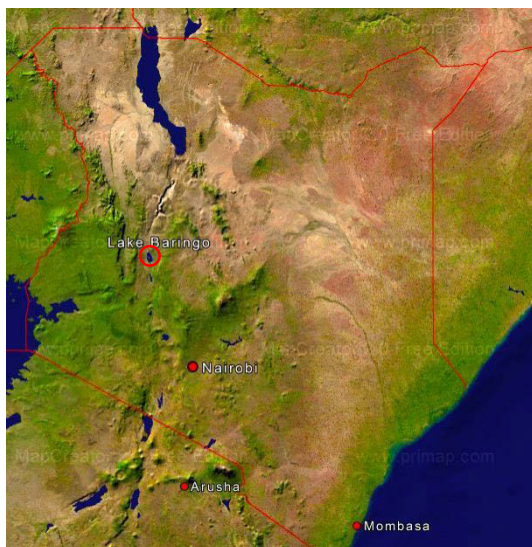


Figure 1: Map of Lake Baringo in Kenya



Figure 2: Detailed Map of Lake Baringo

The lake is geologically characterized by volcanic rocks, which faced high erosion and therefore has caused very high turbidity in the lake (Omondni et al., 2014). The Lake's system is driven by two seasons: the dry (September to February) and the wet (March to August) (Kembenya et al., 2014). Baringo is known for its depth variations, averaging between 3 to 7 meters in depth (Omondni et al., 2011). Famous for its high biodiversity in terrestrial and aquatic ecosystems, Lake Baringo was declared as a Ramsar site in 2001. Particularly remarkably is the appearance of more than 500 bird species, some of which have global conservation status, figure 4 (Britton et al., 2004; Ramsar, 2014). For the local population, the lake functions as freshwater source providing drinking water, food and tourism in this semi-arid area, figure 3 (Ramsar, 2014; Omondni et al., 2014).

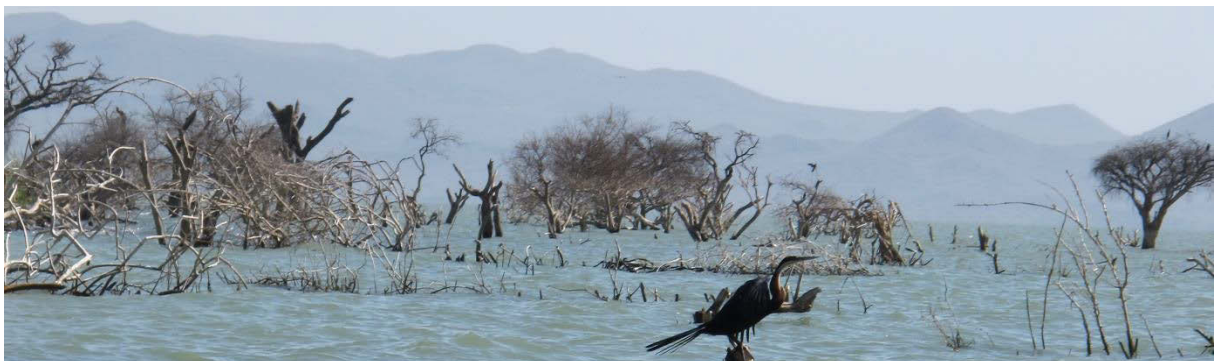


**Figure 3: Impression of Lake Baringo**



**Figure 4: Hunting scene of the African fish eagle *Haliaeetus vocifer***

In the study area, the countryside surrounding Lake Baringo is strongly influenced by anthropogenic activities: The agriculture techniques, excessive grazing and deforestation, first minimized water inflow, and then provoked high erosion and siltation. Moreover, the sharply increasing shifts in water depth are proof that flash floods are a consequence of overgrazing and loss in vegetation (Omondi et al., 2014). Of course, this changes in the morphological, chemical and physical factors of the lake influence water quality, sediment composition and primary production. Biotic factors such as lake vegetation, aquatic organisms and waterbody-dependent species are directly affected by such modifications. Alterations in substrate composition may transform habitats suitable for aquatic organisms until they are no longer habitable, and therefore results in a different species composition (Omondi et al., 2014). For example, the high turbidity has a direct impact on water's light penetration, responsible for determining the euphotic zone and the chlorophyll-a amount of Lake Baringo. The resulting minimized primary production of the lake is represented in its trophic levels (Omondi et al., 2014). Thus, Lake Baringo's extreme turbidity has led to the near extinction of submerged macrophytes and to a lake bed that is virtually unacceptable for the benthic fauna (Hickley et al., 2004). In general, all lakes of the Kenyan Rift Valley (Lake Naivasha, Elementaita, Nakuru, Bogoria, Baringo, Logipi) have been undergoing strong rises in their water levels since 2011. Lake Baringo has undergone such an extraordinary increase in its water level, local villages are beginning to lose their land to water, see figure 5. According to newspaper articles of the Daily Nation Africa (2013), scientists have varying hypotheses to explain this phenomenon: heavy rain events, higher siltation on the lake's ground, and groundwater input caused by terrestrial movements. There are no prognoses for changes in this bleak trend, and the future of the entire area is threatened.



**Figure 5: Flooded trees, rests of the former typically green shoreline of Lake Baringo**

### 3.2 Fish fauna

In total, seven fish species can be found in Lake Baringo, as listed in table 1. Five of those seven, marked with a symbol (\*), are already commercially exploited (Kembenya et al., 2014). In this study, parasitological examinations were carried out on four species, *Oreochromis niloticus baringoensis*, *Barbus intermedius australis*, *Clarias gariepinus* and *Protopterus aethiopicus*, all of which are commercially important fish and major food sources for the local community (Aloo, 2002). Habitat and food resources of *O. niloticus baringoensis*, *C. gariepinus* and *P. aethiopicus* are summarized in table 2 and figure 6, but are unknown for *B. intermedius australis*. Detailed descriptions of these four species are as follows.

**Table 1: Fish species of Lake Baringo; Own table modified on Kembenya et al. (2014) and Seegers et al. (2003)**

| Order                                | Family                           | Species  | English definition |
|--------------------------------------|----------------------------------|--|--------------------|
| Lepidosireniformes<br>(Müller, 1844) | Protopteridae<br>(Peters, 1855)  | <i>Protopterus aethiopicus</i> *<br>(Heckel, 1851)                                   | Northern lungfish  |
| Siluriformes<br>(Rafinesque, 1820)   | Clariidae<br>(Bonaparte, 1846)   | <i>Clarias gariepinus</i> *<br>(Burchel, 1822)                                       | Common catfish     |
| Perciformes<br>(Bleeker, 1859)       | Cichlidae<br>(Bonaparte, 1835)   | <i>Oreochromis niloticus baringoensis</i> *<br>(Trewavas, 1973)                      | Baringo tilapia    |
| Cypriniformes<br>(Goodrich, 1909)    | Cyprinidae<br>(Rafinesque, 1815) | <i>Barbus intermedius australis</i> *<br>(Banister, 1973)                            | Baringo barb       |
| Cypriniformes                        | Cyprinidae                       | <i>Barbus lineomaculatus</i><br>(Boulenger, 1903)                                    | Line-spotted barb  |
| Cypriniformes                        | Cyprinidae                       | <i>Labeo cylindricus</i> *<br>(Peters, 1852)   | Redeye labeo       |
| Cyprinodontiformes<br>(Berg, 1940)   | Poeciliidae<br>(Garman, 1895)    | <i>Aplocheilichthys</i><br><i>sp. nov. "Baringo"</i><br>(Taxonomic status uncertain) | Spotted lambeye    |

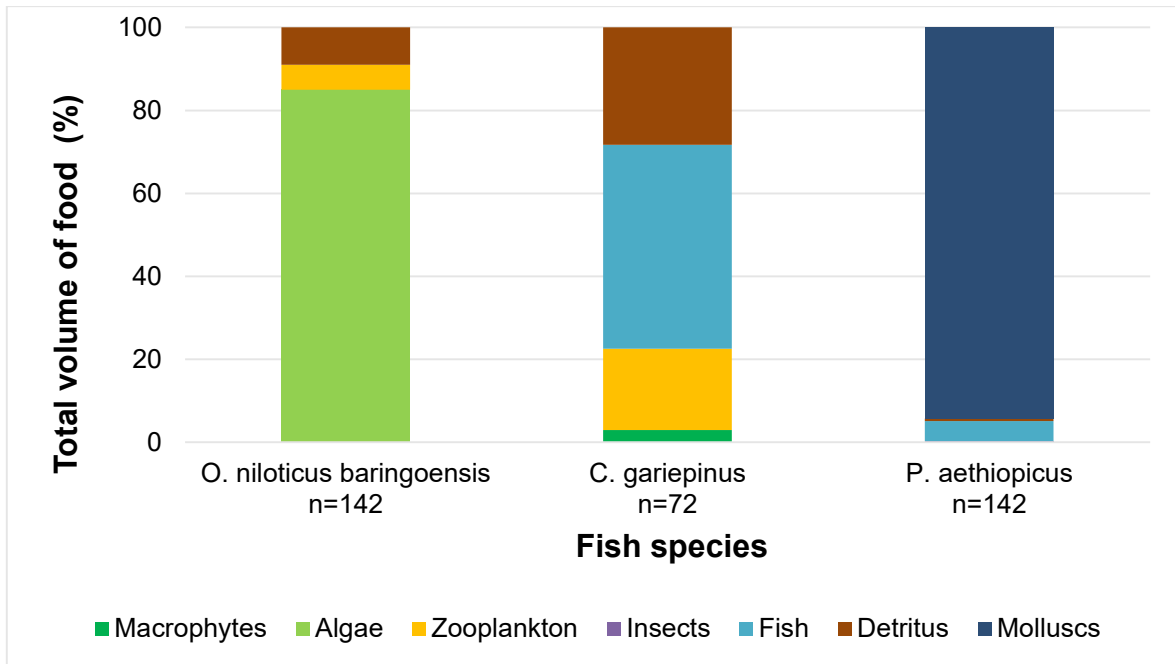


Figure 6: Diet of three fish species (*O. niloticus baringoensis*, *C. gariepinus* and *P. aethiopicus*) from Lake Baringo; Own representation, based on the results of Omondi et al. (2013)

Table 2: Summary of the habitats and feeding strategies of the three fish species *O. niloticus baringoensis*, *C. gariepinus* and *P. aethiopicus*

| Host species                     | Habitat                                 | Feeding strategy | Reference           |
|----------------------------------|---|------------------|---------------------|
| <i>O. niloticus baringoensis</i> | Pelagic zone                            | Herbivorous      | Omondi et al., 2013 |
| <i>C. gariepinus</i>             | Benthopelagic, vegetated marginal pools | Omnivorous       | Omondi et al., 2013 |
| <i>P. aethiopicus</i>            | Benthic zone                            | Omnivorous       | Okeyo, 2003         |



### 3.2.1 *Oreochromis niloticus baringoensis*

*Oreochromis niloticus* (Linnaeus, 1758) is characterized by its compressed body form and an interrupted lateral line (figure 7) (FAO, 2016b). This fish can grow to a standard length of 39.5 cm (Seegers et al., 2003). The dorsal fin contains both spinous (16-17) and soft rays (11-15). During spawning season, the coloration of their fins change into red. *O. niloticus baringoensis* may be found in various freshwater habitats in Africa, with a wide and tolerant temperature regime (FAO, 2016b). This sight-feeding fish prefers to live in pelagic zones with a diet dominated by phytoplankton and benthic algae (Omondi et al., 2013). Okeyo et al. (2003), Hickley et al. (2004) and Britton et al. (2008) declared *O. niloticus baringoensis* as an endemic sub-species of *Oreochromis niloticus* in Lake Baringo.



Figure 7: *Oreochromis niloticus baringoensis* (Baringo tilapia)

### 3.2.2 *Barbus intermedius australis*

The taxonomy and nomenclature for this fish species is confusing and not clearly defined in literature. Though Banister (1973) described the species *B. intermedius australis* in Lake Baringo as an endemic subspecies, figure 8, *Barbus gregorii* (Boulenger, 1911), *B. plagiostomus* (Boulenger, 1902) and *B. erlangeri* (1903) have been listed as misidentifications and junior synonyms of *B. intermedius* (Rüppel, 1835) (Okeyo et al., 2003). The maximum standard length of *B. intermedius* is 48.9 cm. The genus *Barbus* in the Northeastern African region has not been adequately studied yet and more detailed information is not available at this time (IUCN, 2015).



Figure 8: *Barbus intermedius australis* (Baringo barb)

### 3.2.3 *Clarias gariepinus*

An elongated body with a large, bony and compressed head is representative for the genus *Clarias*, as presented in figure 9. Additionally, its mouth is surrounded by four barbels that are the compensating sensory organs for its small eyes. This species can reach up to 150 cm in total length (Seegers et al., 2003). Since the 1970s, *C. gariepinus* has been the most favored catfish species for aquaculture and Kenya is one of its main exporters worldwide. Furthermore, this versatile fish species occurs natively in a wide variety of aquatic systems, such as lakes, rivers, swamps and floodplains. Additionally catfish have a special breathing system that enables them to survive in habitats with very low oxygen conditions (FAO, 2016a). According to Omondi et al. (2013), *C. gariepinus* is an omnivore fish, feeding on insects, worms, crustaceans, fish, zooplankton, detritus and aquatic plants in Lake Baringo (Omondi et al., 2013).



Figure 9: *Clarias gariepinus* (Common catfish)

### 3.2.4 *Protopterus aethiopicus*

*Protopterus aethiopicus*, also known as northern lungfish is a fish with an elongated body that tapers to its tail. The coloration of *P. aethiopicus* shifts between dark-grey to yellowish-grey and they are often covered in dark spots (CABI, 2013). Lungfish can reach a maximum length of 200 cm (Seegers et al., 2003). Other characteristics include filamentous and fine pectoral and pelvic fins (only soft rays). Moreover, adults and juveniles are missing teeth and external gills, as shown in figure 10. They do not have gills, but lungs as their respiration organs. Because of this special breathing system, lungfish are able to survive long stents in extreme habitats low in oxygen. Specimens are able to establish themselves in a cocoon buried in the mud of dried up ponds, where they may survive until the next rain season brings water for as long as several years (CABI, 2013). The marbled lungfish is a carnivorous, non-visual feeder (Seegers et al., 2003), (CABI, 2013). Their diet is adapted to the local food content in aquatic systems, consisting of mollusks, insects, crustaceans, worms and fish (Omondi et al., 2013).



Figure 10: Mouth of *Protopterus aethiopicus* (Northern lungfish)

### 3.3 Fishery

Aloo (2002) reports that *O. niloticus baringoensis* is up to 80% of a fisherman's catch in Lake Baringo. All other species are caught in much lower numbers: *P. aethiopicus* (7.6%), *C. gariepinus* (8.9%), *B. intermedius australis* (3.1%), and *L. cylindricus* (0.1%). *L. cylindricus* is classified as endangered, and *B. lineomaculatus* and *A. spp.* are both classified as rare (Britton et al., 2004). Of course, occurrence and abundance are influenced by year and season (Hickley et al., 2004). Commercial catches change with fish behavior, affected by dry and wet season (Odada & Olaga, 2002). *B. lineomaculatus*, a very small and largely riverine fish, are rarely caught by commercial fishers. The building of dams on the inflow rivers of Lake Baringo is likely to have an influence on the downturn of *L. cylindricus* and *B. intermedius australis*, which are potamodromous and undergo spawning migrations to these rivers (Hickley et al., 2004). The cichlid fish species *O. niloticus baringoensis* formed the basis for all sustainable fisheries around 1950. Since then, fisheries have put more and more pressure on the lake's already threatened fish populations. Commercial fishing has been closed two times already (in 1993 and 2002) to give fish populations time to recover. Nevertheless, the number of catches remains low. *O. niloticus baringoensis*, especially, illustrates an ongoing decline in population size, though the reasons for which, are controversial (Okeyo, 2003). Odada & Olaga (2002) state the decline of tilapia may be more linked with the lake's level fluctuations than with overfishing. In contrast, Britton et al. (2008) announced that the environmental changes they are being exposed to may actually be benefitting the fish, as the rise in the lake's water level improves nutrient input and food availability. Regardless, ongoing lake level fluctuations, high siltation and the disturbance of inflow regime may have influenced the decline of the Baringo fishery (Hickley et al., 2004).

So far, *C. gariepinus* and *P. aethiopicus* have been filling up the gaps of *O. niloticus baringoensis* in the fishing market (Seegers et al., 2003). In Kenya, and especially in Lake Baringo, *P. aethiopicus* is described as an invasive species. Three individuals were introduced accidentally into Lake Baringo in 1975. Thus far, *P. aethiopicus* seems to have had no direct or indirect impact on the lake's original fish community. Interestingly enough though, this fish species seems, in contrast to the lake's other fish species, to have not suffered from environmental stress, and its population size continues to increase (Okeyo, 2003).

### **3.4 Methods**

Here, the sampling design for this study will be explained and separated into three different parts: fish collection, parasitological examination techniques, taxonomic identification, terminology and statistical definitions.

#### **3.4.1 Fish collection**

The purchase of four commercial fish species (*O. niloticus baringoensis*, *P. aethiopicus*, *G. gariepinus* and *B. intermedius australis*) at Lake Baringo was organized with local fishermen at Village Kampi Samaki. The fishermen accessed the lake via traditional canoes and caught the fish with long-lines and gillnets. The sample of 101 fish specimens was obtained in March - April 2015. Three species (*L. cylindricus*, *B. lineomaculatus* and *Aplocheilichthys spp.*) in Lake Baringo were not included in this research because the species were either too rare, too small to be caught by commercial fishermen, or declared endangered. Fishermen expressed also difficulties in catching a high number of the species *P. aethiopicus* and *G. gariepinus* at the time of year this study was conducted (end of the dry season) and less than 20 specimen of each species were caught, even though we considered our minimal sample size is 30 individuals per species in order to obtain a statistically significant database (Marques & Cabral, 2007). In the first week, fish examinations were processed locally at Kampi Samaki. Afterwards, dead fish were transported on ice or, if they were alive, in an appropriate fish tank with an adequate oxygen supply to at laboratory in the Biological Sciences Department at Egerton University. There, all fish were killed via cervical dislocation according to the Austrian and Kenyan animal protection act (§ 13 appendices G. TSch-Schlacht-V; §8 appendices prevention of cruelty to animals act).

#### **3.4.2 Parasitological examination techniques**

Species identification and measurements were completed first, according to the description of Zokhov et al. (2007). The focus of this study is on the endoparasitic helminth groups: digenean trematodes, cestodes, nematodes and acanthocephalans. Nevertheless, ectoparasitic examinations were carried out before dissecting fish. Problematic with ectoparasites is, that very fresh and recently caught fish would be necessary, because most Protozoa immediately leave the dead host (Hoffman, 1967). The bodies of the fish, including the gills, mouth, skin and fin surfaces were examined

for remaining protozoans, monogeneans and crustaceans (Roberts 1985). Different helminth larval stages were investigated in internal body organs (organs, abdominal cavity and digestive tract) using standard methods (Zokhov et al., 2007). Furthermore, the gastrointestinal/digestive tract was removed, cleaned, stretched, sliced and analysed for helminths (cestodes, nematodes, and acanthocephalans) (Zhokhov et al., 2007). Additionally, a random sampling for parasites was conducted in the eyes, kidneys, livers and brains. For this random sampling, the eyes were first removed into a Petri dish with saline water, cut open and observed for any movements of digenean larvae. Next, a small piece of the brain was taken out, washed with saline and examined for myxosporeans and trematodes metacercariae. Finally, the procedure used for the brain was used for the kidney and liver to investigate for larval helminths (Lasee et al., 2004).

Digenean trematodes, nematodes and cestodes were finally soaked in 70 – 80 % ethanol, digenean trematodes were stained with boraxcarmin following the method of Roberts (1985), and all were preserved in the National History Museum of Vienna.

### **3.4.3 Taxonomic identifications**

For this study, taxonomic identifications were mostly limited to genus level because the larval stages of the parasites could not be distinguished by species. Larval forms without visible diagnostic characteristics, such as sex organs, cannot be differentiated with certainty among taxa (Hoffman, 1967). For most larval stages of parasites, like *Eustrongylides sp.* for example, the adult form of the parasite and therefore dead final hosts, piscivorous water birds, would be necessary to achieve reliable results (Paperna, 1996; Moravec, 1998). In the cases of the trematode metacercariae and cestoda larvae, distinguishing them on the level of their supragenus, genus or species is already too challenging and leads to many misidentifications. For all that reasons, species identification species was only carried out for the Crustacean parasite *Dolops ranarum*. For the species *Contraecaecum sp.*, *Eustrongylides sp.*, *Clinostomum sp.* and *Euclinostomum sp.*, all difficult to identify on a species level in their larval stages, DNA sequencing is being carried out in cooperation with the University of Veterinary Medicine in Bologna, Italy and are still in process.

### **3.4.3 Terminology**

Ecological terms are explained in detail to give a better understanding of subsequent used definitions and analyses.

#### **Ectoparasite:**

Ectoparasites infect the outer body parts of fish, like the skin, gills and rectum, all of which are in strong contact with the environment, but are not found within the body (Zander, 1998).

#### **Endoparasite:**

Endoparasites live within the body and are found in various body cavities and organs (Zander, 1998).

#### **Helminths:**

Helminths is the definition for parasitic worms and includes the parasitic groups digenean trematodes, cestodes, nematodes and acanthocephalans (Zander, 1998).

#### **Intermediate host:**

One or more intermediate hosts are necessary for some parasite to complete its life cycle, as their developmental stages change within the intermediate hosts. Reproduction within intermediate hosts is sometimes possible for specific parasite species, but only via agametic methods (without gametes) (Esch & Fernandez, 1993).

#### **Definitive or final host:**

A parasite requires its definitive or final host to become sexually mature (Esch & Fernandez, 1993).

#### **Direct life cycle:**

A one-host cycle, in which no intermediate host is required for the parasite's development (Esch & Fernandez, 1993).



**Indirect life cycle:**

A life cycle that requires at least one, and often more than one, intermediate host (Esch & Fernandez, 1993).

**Autogenic parasites:**

Autogenic parasites have a life-cycle, in which all development takes place within aquatic ecosystems (Diaz & Munoz, 2010; Criscione, 2005).

**Allogenic parasites:**

Allogenic parasites have some development stages within the aquatic system, but always finally mature within terrestrial animals (Díaz & Muñoz, 2010; Criscione, 2005).

**Infracommunity level:**

All individuals of one parasite species in or on a single host (Zander, 1998; Poulin, 2006).

**Component community level:**

The sum of all infracommunities, or parasites of all species, within a host population (Zander, 1998; Poulin, 2007).

#### 3.4.4 Statistical definitions

The application of specific quantitative statistics (prevalence, mean intensity, abundance, dominance, biodiversity indices, and aggregation distributions) are used to describe ecological factors.

##### **Prevalence (P):**

Proportion of infected hosts of those examined: the number of infected hosts, of one species, taxonomic group or development stage, divided by the number of hosts examined in, and presented as a percent (Bush et al., 1997).

$$P = \frac{\text{Number of infected fish}}{\text{Total number of fish examined}} * 100$$

##### **Intensity (I):**

Number of parasites of one species, taxonomic group or development stage per infected host (Bush et al., 1997).

##### **Mean Intensity (Mi):**

Mean number of parasites of one species, taxonomic group or development stage found in an infected host (Bush et al., 1997).

$$MI = \frac{\text{Number of parasites}}{\text{Number of infected fish}}$$

##### **Abundance (Ab):**

Total number of parasites of one species, taxonomic group or development stage found on hosts, divided by the number of hosts that were examined (Bush et al., 1997).

$$Ab = \frac{\text{Number of parasites}}{\text{Number of examined fish}}$$

**Dominance (d):** The number of parasites of one species, taxonomic group or development stage of one fish species, divided by the total number of specimens of all species in the infracommunity (Bush et al., 1997).

$$d = \frac{\text{Abundance of a parasite species}}{\text{Sum of the abundance of all parasite species}} * 100$$

**Evenness:**

Evenness is the equal number of specimens per species in the same ecosystem (Magurran, 2004).

**Diversity indices:**

*“Biodiversity represents the variety and heterogeneity of organisms or traits at all levels of the hierarchy of life, from molecules to ecosystems”* (Morris et al., 2014, p. 3514). There exist various indices to quantify biodiversity that differ in their theoretical formulae and methods of interpretation. Some of these indices incorporate other factors such as species abundance and richness (Morris et al., 2014). In this study, four indices are used to express the parasitic diversity in Lake Baringo: Richness, Shannon Wiener Index (H'), Simpson's index (D) and Berger Parker index (d).

**Richness:**

Species richness is defined as the number of species that are known to exist (Whittaker, 1972). It is a very simple metric to express species diversity and is one of the most used (Morris et al., 2014). In this study this term is used to describe the findings of parasites species of fish in Lake Baringo.

**The Shannon Wiener Index (H'):**

Calculated from the equation:

$$H = - \sum_{i=1}^s p_i * \ln p_i,$$

where  $p_i$  is the proportion of individuals belonging to the  $i$ -th species in the dataset and represents the relative abundance of a species (Magurran, 2004). If both the number of individuals and the species relative abundance are increasing, the value of the index gets higher. The maximum is reached when a given number of species indicate the same evenness (Morris et al., 2014).

**Simpson's index (D):**

Presents the probability that any two individuals drawn at random from an infinitely large community will belong to the same species and is calculated as:

$$D = \sum p_i^2$$

where  $p_i$  is the proportion of individuals in the  $i$ -th species (Magurran, 2004). As  $D$  increases, diversity decreases. The Simpson's index measures the evenness, and is a high number when there is an equal number of individuals per species (Morris et al., 2014).

**Berger Parker Index (BP):**

Numerical measures of the most abundant species, calculated as:

$$BP = \frac{N_{max}}{N}$$

where  $N_{max}$  is the number of individuals of the most abundant species, and  $N$  is the total number of individuals in the sample (Magurran, 2004).

**Dispersion Spectrum:**

The dispersion spectrum, determined by the relationship between prevalence and mean intensity, shows three different distribution patterns: underdispersion, overdispersion and random dispersion, explained in detail above (Anderson, 1993). These three distributions explain how parasite individuals of one species are aggregated among the host population. Nevertheless, we always have to keep in mind that even parasitic distributions vary within time, some patterns in aggregation are always recurring (Poulin, 2007). Among most cases, aggregation for fish parasites is considered as an overdispersion, with a small number of infected hosts, which harbor parasites even at high infection levels (Pennycuik, 1971; Poulin, 2006).

**(Positive/Negative) Binomial distribution = underdispersion:**

The binomial distribution is a probability distribution, with the parameters  $n$  and  $p$ , that expresses the probability  $p$  of the number of successes in a series of  $n$  independent experiments, with two possible outcomes (i.e. success or failure) (Schäfer, 2015; Heath, 1995). The positive binomial distribution, in terms of

parasitology, is known as underdispersion: Most hosts harbor the same number of parasites regularly. The negative binomial distribution presents heterogeneity and overdispersion/aggregated distribution patterns: Most hosts are uninfected except for a few that harbor almost all of the parasites (Anderson, 1993).

### **Poisson distribution = random / independent dispersion**

In binomial distribution, if the limit for  $n$  is set towards infinity and for  $p$  towards zero while the product of  $n$  and  $p$  is constant the poisson distribution is received (Schäfer, 2015). The poisson distribution is a discrete probability distribution, with only one parameter  $\mu$ , which describes the occurrence of a known number of events in a given interval of time, plane or space (Schäfer, 2015; Blaesild & Granfeldt, 2002). This type of distribution is used to explain distributions of random events in large populations (Stephenson, 2016). This means, that in a poisson distribution, parasites are only expected by chance and independently (Anderson, 1993).

### **Akaike Information Criteria (AIC):**

The AIC is an information-theoretical approach used to compare models. For this study the AIC was used to compare the positive/negative binomial and Poisson distribution as possible models for the data. For this reason, the goodness of fit of the models to the data was measured to find the most suitable distribution of parasites among their host population. It not only indicates how well the model fits the ecological data, but also penalizes model complexity by taking into account the number of parameters in each model (Cameron & Trivedi, 2005). For small sampling sizes, the Akaike Information Criterion ( $AIC_c$ ) is used to minimize mistakes. The formula is

$$AIC_c = \frac{-2(\log\text{-likelihood})+2K+(2K(K+1))}{(n-K-1)}, \text{ where } K = \text{parameters and } n = \text{the sample size.}$$

The lowest AIC value is the best model interfered on the available data. Two additional measures, delta  $AIC_c$  ( $\Delta_i$ ) and Akaike weights ( $\omega_i$ ), can also be used to indicate the goodness of fit of a model, where smaller is better. Delta  $AIC_c$   $\Delta_i$  is a simple measurement for each model relative to the best model, in which  $\Delta_i = AIC_{ci} - \min AIC_c$ . The interpretation of  $\omega_i$ , which are the ratio of  $\Delta_i$ , indicates the probability, that a model is the most suitable among all models. For example, 0.9 of  $\omega_i$  for a model suggests that the model has a 90 % chance of being the best fitting model (Mazerolle, 2004).

### 3.5 Analyses

First, it is important to clarify that all definitions in this chapter are given in detail in chapter 3.4. All numerical results were analysed using Microsoft Excel 2015 and the statistical program R (Version 3.3.1) and rStudio.

For the parasitic community, the typical quantitative description parameters, such as prevalence (P), mean intensity (MI)  $\pm$  standard deviation (Sd), and abundance (Ab) was calculated for each parasitic taxon (Bush et al., 1997; Zander, 1998.) The total prevalence of all parasites per fish species was calculated using the Wilson score interval and a confidence level of 95 %, in light of the small sampling size. In addition to the standard definitions just mentioned, dominance was measured (Bush et al., 1997). Furthermore, some ecological details, such as their living forms (ecto-/endoparasites), life-cycles (1<sup>st</sup> and 2<sup>nd</sup> intermediate and final host), status (i.e.: autogenic or allogenic) and type as generalist/specialist are designated for each species based on the literature review. Species diversity was measured by applying the Shannon Wiener (H'), Simpson's (D) and Berger Parker (d) indices (Magurran, 2004). The Shannon Wiener Index was used as a quantitative measure to represent how many different species were in the entire dataset, including the evenness of a parasite species distribution in the lake. The Simpson's index was used to evaluate each parasite species' proportion in relation to all parasite groups measured. The Berger Parker Index was used to indicate the proportional abundance of the most dominant species of the population (Morris et al., 2014). We also calculated the maximum infracommunity richness, because the variation of parasite species richness and composition within a host population may vary among individuals as different communities are formed (Poulin, 1996). Additionally, host-parasite interactions were examined for the most prevalent parasite groups by using linear regression models with fish size as independent variable and parasite abundance as dependent variable. There theoretically exist three possible distribution patterns (overdispersion, underdispersion and independent distribution) occurring in parasite distributions in a host population (Anderson, 1997). However, Poulin (2007) suggests, that parasitic distributions are always following the same pattern of aggregation: namely overdispersion. To prove this pattern and to find the pattern of aggregation best describing the data of the two parasite groups most frequently found, a model selection

approach based on the Akaike information criterion ( $AIC_c$ ) was used. Therefore, the three possible distributions were set as candidate models. The maximum likelihood and  $AIC_c$  weights were estimated to evaluate the quality of each model and the distribution type that best fit the data chosen.

Finally, the standard quantitative parameters and parasite community richness were compared with lakes of other East African countries, including Ethiopia, Kenya, Tanzania, Uganda and Rwanda.

## 4 Literature review

All recorded fish parasites from Lake Baringo are explained in detail to give further information on their taxonomic classifications (to genus or species level) (Bykhovskaya-Pavlovskaya et al., 1964), biology, host specifics and geographical distribution patterns.

### 4.1 Protozoa

Phylum: Protoza (Goldfuss, 1808)

Protozoans are primitive unicellular eukaryotes belonging to the kingdom Protista (Lom & Dykova, 1992). Worldwide, there exist more than 45,000 taxa, 10,000 of which are parasites. Protozoan infections are not only famous because of well-known human tropical diseases, such as malaria and the sleeping sickness, but they also may provoke disease and fitness declines in fish (Cox, 1993). Protozoan parasites are very sensible to abiotic environment conditions and cannot persist in the environment without a host. A common characteristic of the complex life cycle of protozoans is their fast reproduction in large numbers via asexual or sexual means (O'Donoghue, 2010). Additionally, this parasitic group developed abilities to antagonize the immune response of a host, prolonging infection time. Protozoans are separated into four groups, distinguished from each by their movement patterns: flagellates, amoebae, ciliates and sporozoans (Cox, 1993).

#### 4.1.1 Myxobolidae

Class: Cnidosporidia (Doflein, 1901)

Order: Myxosporidia (Bütschli, 1881)

Family: Myxobolidae (Thelohan, 1892)

Genus: *Myxobolus* (Bütschli, 1881)

Species: *Myxobolus sp.*

Taxa of the Myxobolidae are the most frequent parasitic group of protozoans. They have spores and infect fish and amphibians. There exist already 453 species of *Myxobolus spp.* known to specifically infect fish (Lom & Dykova, 1992). Species identification occurs on the basis of the spore form (Hoffman, 1967). Specimens of this genus occur in a wide range of fish species in Africa, but are most commonly found in the families Cichlidae and Cyprinidae: for instance, *Tilapia spp.*, *Labeo spp.* and *Barbel*



*spp.* (Paperna, 1996). Even though detailed information regarding their biology and life cycles is still unknown, we do know that all taxa have an indirect life cycle, with an actinosporean development stage (throphozoite) in the oligochaete species, as presented in figure 11 (El-Mansy & Molnar, 1997; Abowei & Ezekiel, 2011a). Infections with myxosporidae can be aggressive, causing serious skin infections and tissue hypertrophy due to histopathological changes, as it happened at Lake Victoria and Lake George in Kenya (Paperna, 1996; Lom & Dykova, 1992). The exact location of *Myxobolus spp.*' infection depends on the species; some are very site specific and others are more generalized (Lom & Dykova, 1992). For example, in the family Cyprinidae, *Myxobolus spp.* is known to infect the fins and gill filaments of juveniles. *Myxobolus* cysts may be found in the interior organs, body cavity, and muscles, as shown in figure 12. Although host fish exhibit some signs of infection, they seem to be, overall, in good condition. Only when there is an extremely high number of cysts in specific body parts may the health of a host fish be seriously compromised (Abowei & Ezekiel, 2011a). For instance, if the cysts are located in masses in the mouth or gills of a fish, its feeding and breathing activity may be limited (Paperna, 1996).

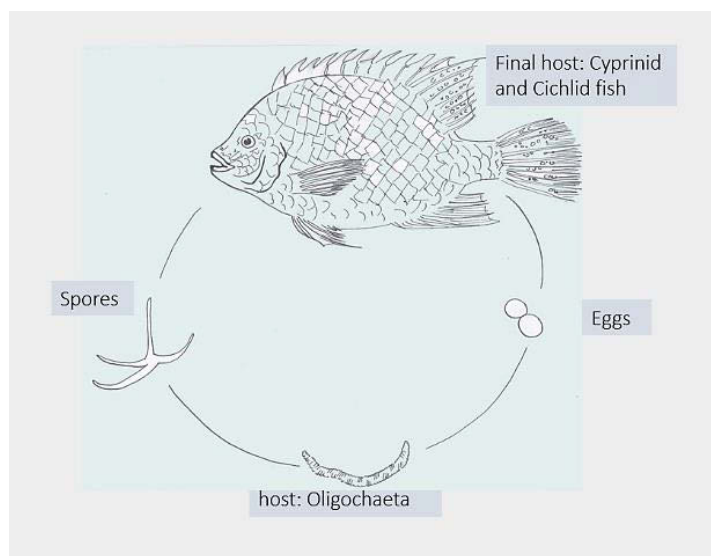


Figure 11: Life cycle of *Myxobolus sp.*

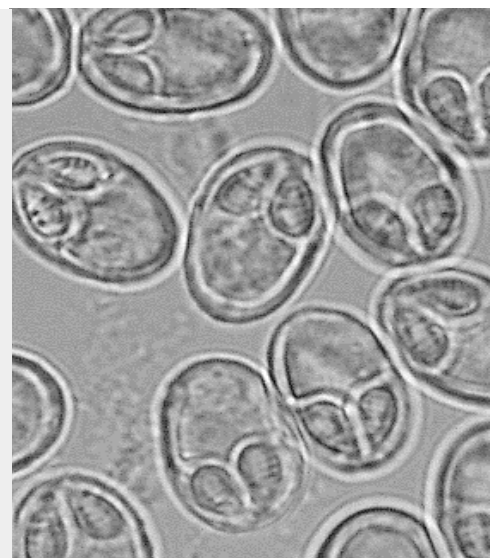


Figure 12: *Myxobolus sp.*

## 4.2 Monogenea

Phylum: Plathyhelminthes (Gegenbaur, 1859)

Class: Monogenea (Carus, 1863)

More than 20,000 taxa, separated into 14 families, are known to affect invertebrates and vertebrates. Most of them are specialists and host-specific (Poulin, 2006). Four families of Monogenea are found on marine and freshwater fish: Gyrodactylidae, Dactylogyridae, Ancyrocephalidae and Capsalidae (Sauermost, 2002). Monogeneans have a small, flattened body form and, typically, body appendages like suckers, glands and clamps to attach themselves on the host's skin, gills and fins (Paperna, 1996). Another important fact is that all adult forms are hermaphroditic, with both female and male reproductive structures, and nearly all of them are ectoparasites, infecting gills or skin (Reed et al., 2015). Those that are not ectoparasites are endoparasites that specialized for infecting organs in direct contact with the environment, like the urinary bladder and mouth cavity (Sauermost, 2002). This parasite group has a very simple and direct life cycle; the parasites infect the final host directly, and has no intermediate hosts (Dogiel et al., 1961). A lot of attention has been directed to this parasite group because, at high infection rates, they are often linked with fish mortality in aquatic farming (Sauermost, 2002).

### 4.2.1 Dactylogyridae

Class: Monogenea (Carus, 1863)

Order: Dactylogyridea (Bykhovskii, 1933)

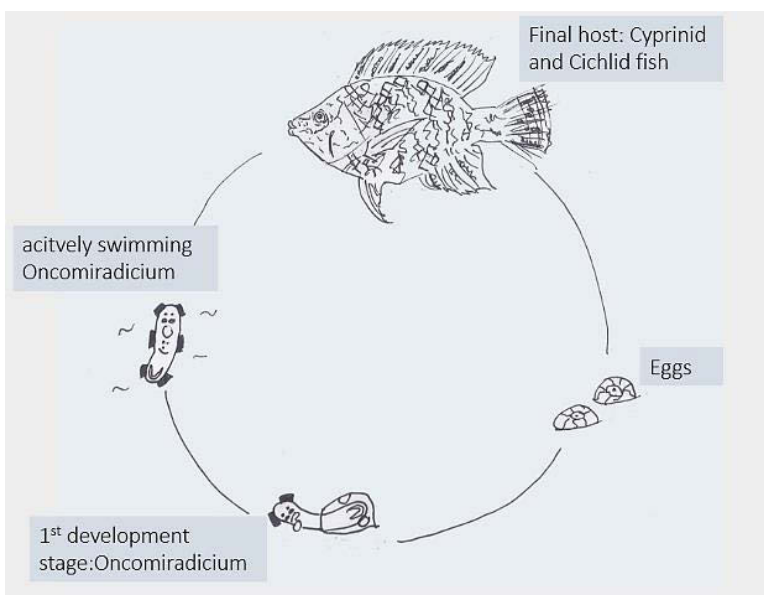
Family: Dactylogyridae (Yamaguti, 1963)

Genus: *Dactylogyrus* (Diesing, 1850)

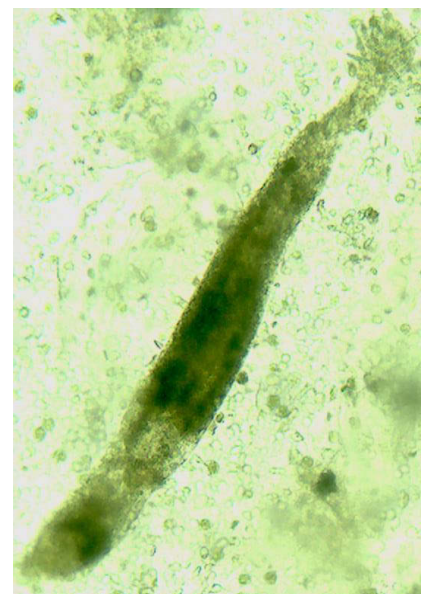
Species: *Dactylogyrus sp.*

This ectoparasitic and strongly host-specific group includes 221 different taxa (SSRI, 1962; Hoffman, 1976). *Dactylogyrus sp.* are characterized by two pairs of eyespots and marginal hooks (normally around 12-14), see figure 14. They typically have a short life cycle (40-45 days) and a fast development through all of their life stages. Their reproduction mode is oviparous. Their eggs sink in a water column and hatch with appendages in fish mucus or organic material. The completion of their direct life cycle from egg to adult is temperature dependent with an optimum of 22 – 25 degrees. The form following the impervious egg is a free-swimming, silica covered, larvae stage

(oncomiracidia) (figure 13). *Dactylogyrus* spp. larvae already have the ability to migrate actively to their host and preferred location: the gills of freshwater cyprinids (Reed et al., 2015). Three species of *Dactylogyrus* (*D. vastator* (Nybelin, 1924), *D. anchoratus* (Dujardin, 1845) and *D. extensus* (Mueller et v. Cleave, 1932)) infect carp in high rates, leading to mass death in aquaculture, particularly in Europe. This pest, also known as the “Karpfenbrutkrankheit” causes severe damage to the gills of juvenile carps (Reichenbach-Klinke, 1975). In ponds, there are no limits to the concerns of transmission and reproduction due to the high densities of fish (Paperna, 1996). *Dactylogyrus* spp. are also infecting fish in natural systems, but not in the same large quantities (Reichenbach-Klinke, 1975). So far, there are no statements regarding the real problem of fish pests in natural water bodies due to the presence of *Dactylogyrus* sp. in Africa. Research has only been conducted in fish farms, in which the fry stages of fish were shown to have a high mortality rate due to *Dactylogyrus* sp. infections. High infection rates on the gills are leading to respiration stress under low-oxygen conditions (Reed et al., 2015).



**Figure 13: Life cycle of *Dactylogyrus* sp.**



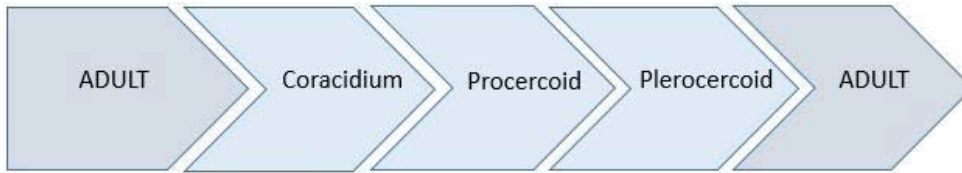
**Figure 14: *Dactylogyrus* sp.**

### 4.3 Cestoda

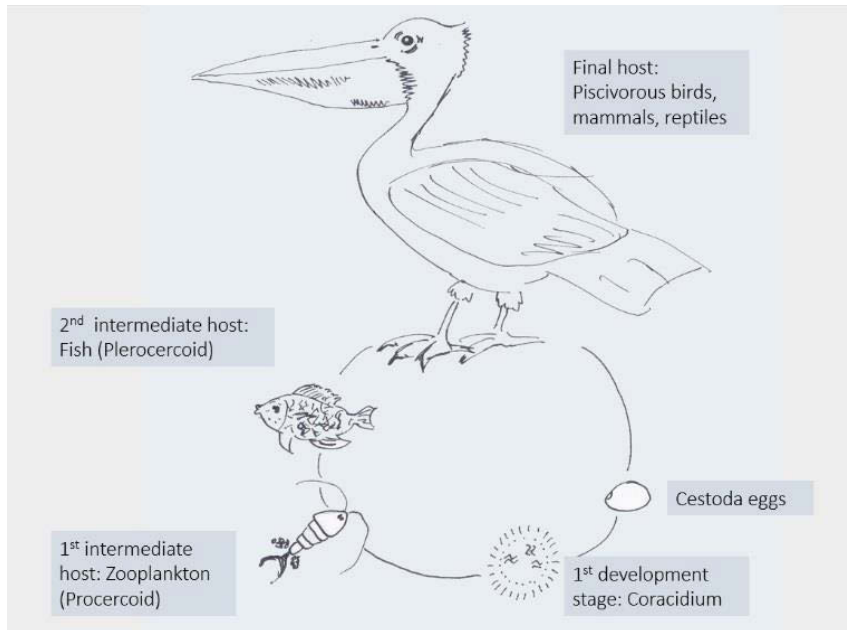
Phylum: Platyhelminthes

Class: Cestoda (Rudolphi, 1808)

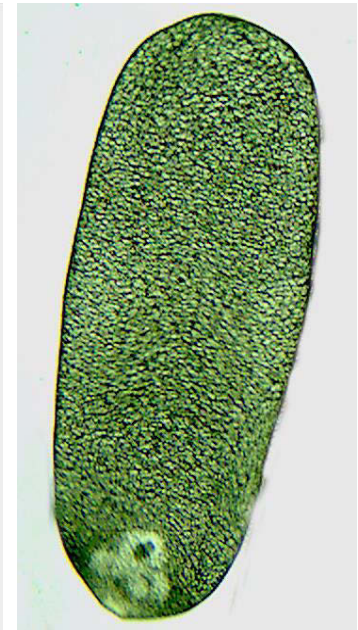
All 5,000 species of cestodes are endoparasites in vertebrates. In general, cestoda are known to be generalists regarding their host requirements (Poulin, 2006). About 40 species (adult and larval stage) exist in five families of native African fish: Amphiliniade, Caryophyllaeidae, Bothriocephalidae, Ptychobothriidae (Paperna, 1996). The body morphology of adult tapeworms is flattened with a scolex (attachment organ) at one end, and the neck and special segments are known as proglottides or unsegmented strobili. They also do not have a digestive system and are hermaphrodites (Whitfield, 1993). Tapeworms have an indirect life cycle (figure 16) that is more or less the same for all cestodes, requiring one or more intermediate hosts before they can become sexually mature within their definitive host (Dogiel et al., 1961). Paperna (1996) describes two different first intermediate hosts for tapeworms: copepods and annelids (*Tubifex*) for monozoic cestodes. Normally, the freshly hatched larvae, the so-called coracidium is taken up by copepods, where it transforms into the next development stage (proceroid), shown in figure 15. If the first intermediate host is swallowed by a second intermediate host, which are mostly fish, it passes into the next development stage (plerocercoid). If the infected fish is eaten by a water bird, the final host, the plerocercoid matures into the adult parasite (Dogiel et al., 1961). In fish two development stages of cestodes are appearing: rarely, the adults in intestines (definitive host), and mostly, the plerocercoid larvae in viscera and musculature (intermediate host) (Florio et al., 2009). The larvae (plerocercoid) are often encysted in body cavities, organs or the muscle of a fish, figure 17. Strong infections of tapeworms cause damage to the fish's health. Plerocercoids, which migrate in the vital organs of fish, may produce adhesions leading to sexual sterility, a lower number of eggs, and a damaged metabolism (Hoffman, 1976). Some cestodes may be a possible risk for human health. For instance, a fish born zoonosis called Dipyllobothriasis is caused by the tapeworm *Dipyllobothrium sp.* (Reichenbach-Klinke, 1975).



**Figure 15: Development stages of cestodes**



**Figure 16: Life cycle of cestodes, with zooplankton as its intermediate host and water birds as its final host**



**Figure 17: unidentified cestode larvae**

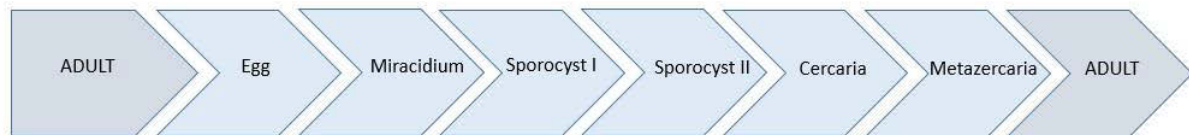
#### 4.4 Trematoda

Phylum: Platyhelminthes

Class: Trematoda (Rudolphi, 1808)

Trematodes have indirect life cycles that are complex and vary among different species. In fish, this fluke may occur as an adult or in one of its various development stages (Dogiel et al., 1961). Trematodes metacercariae, figure 19, may be found on the skin and gills of many fish species, most commonly the juvenile fish of the family Cichlidae (Paperna, 1996). The first intermediate host are mollusks, where an asexual multiplication happens. Fish is its second intermediate host, and it finally matures in some fish species, water birds, mammals and reptiles (Hoffman, 1976). Within its different hosts, trematodes undergo different stages of development (miracidium, sporocysts, rediae, cercariae and metacercarie), as shown in figure 18 (Paperna, 1996). Cercariae penetrate their hosts actively, not via food uptake (Dogiel et al.,

1961). This means that the two free motion stages, miracidium and cercariae, are able to swim or migrate actively with the help of ciliates in the waterbody, infecting their host directly by migrating into the fish's tissue (Paperna, 1996). This active infection causes damage to the host's tissue, and high infection rates may even cause death. On the other hand, single infections seem to be harmless for the fish's health (Hoffman, 1976).



**Figure 18: Development stages of trematodes**



**Figure 19: trematode metacercariae of fish gills**

#### 4.4.1 Diplostomidae

Class: Trematoda (Rudolphi, 1808)  
 Order: Strigeidida (La Rue, 1926)  
 Family: Diplostomidae (Poirier, 1886)  
 Genus: *Diplostomum* (Brandes, 1822)  
 Species: *Diplostomum sp.*

*Diplostomum spp.* may be located in many different organs of fish, like the eye lens and brain. Diplostomidae have an indirect life cycle, as presented in figure 20 : the eggs hatch into the first larval stage (miracidium), which is then able to swim and actively infect the first intermediate host, mollusks. First of all, when the miracidium is implemented in the water snail, it reproduces asexually and progresses through the next three larval stages (sporocysts, rediae and cercariae). The fork-tailed cercariae can swim to a second intermediate host's tissue, actively permeates the skin and

migrates to specific organs of the fish, where they finally encyst and develop to the metacercariae, figure 21. Adult forms of Diplostomidae exist in their final hosts, water birds (SSRI, 1962).

Fish mostly act as secondary hosts, as few species have fish as their definitive host. High infection rates of *Diplostomum spp.* may be leading to negative impacts on the host's health, no matter where it is located. Some metacercariae are of significant epizootic importance, provoking for instance serious diseases like eye blindness in fish (*Diplostomum spathaceum* (Rudolphi, 1810)) (SSRI, 1962). Skin infections of the genus *Diplostomum* are the reason for the so-called "black spot disease" of fish (Paperna, 1996). When metacercariae occur in the brain and spinal cord in fish, they can cause various negative impacts on brain structures, such as inflammations and nerve disruptions (Mwangi, 2011).

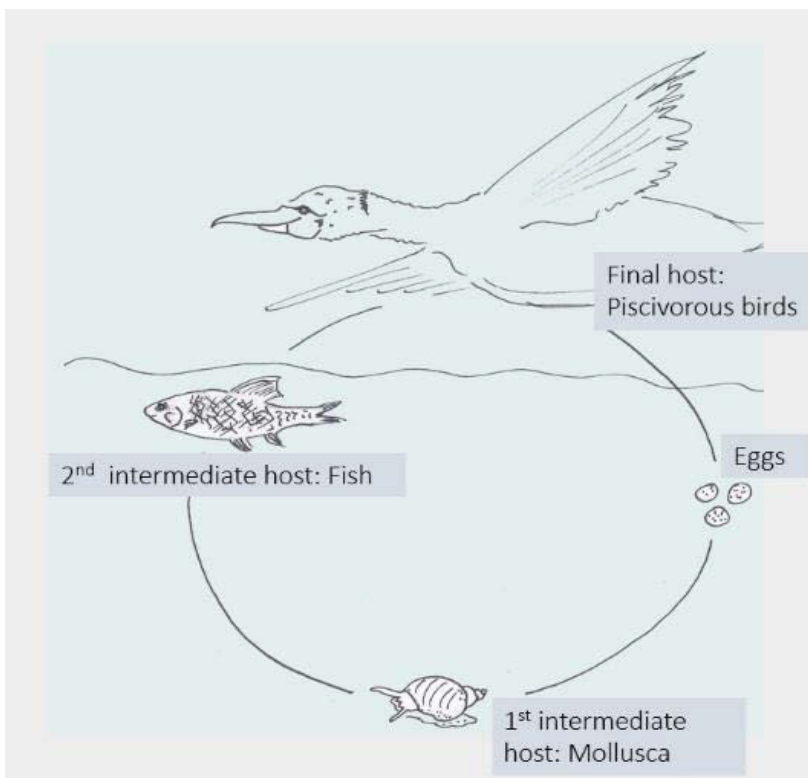


Figure 20: Life cycle of *Diplostomum sp.*



Figure 21: *Diplostomum sp.* of fish brain

#### 4.4.2 Clinostomatidae

Class: Trematoda

Subclass: Digenea (Carus, 1863)

Family: Clinostomatidae (Lühe, 1901)

Genus: *Clinostomum* (Leidy, 1856) and *Euclinostomum* (Rudolphi, 1809)

Species: *Clinostomum sp.* and *Euclinostomum sp.*

Taxa of Clinostomatidae occur frequently in the family Cichlidae, but also in some species of the families Cyprinidae and Siluridae. Parasite specimens of the family Clinostomatidae are common in Africa, recorded in Ethiopia, Uganda and Kenya. Especially infections with *Euclinostomum sp.* are common for catfish (Paperna, 1996). The metacercaria of the two genus types *Clinostomum* (figure 23) and *Euclinostomum* (figure 24) can be distinguished from each other in morphology (suckers) and the infected organ, as presented in table three. Both are macroparasites, which can grow to a maximum size of 3 to 7 mm (Florio et al., 2009).

**Table 2: Characteristics of *Clinostomum complanatum* and *Euclinostomum heterostomum* in *Oreochromis niloticus* (Source: Own table based on Florio et al., 2009)**

|   | Morphology         | Location                 |
|---|--------------------|--------------------------|
| <i>Clinostomum heterostomum</i><br>(Rudolphi, 1814)   | Yellowish          | Gill arch, skin          |
| <i>Euclinostomum heterostomum</i><br>(Rudolphi, 1809) | Yellowish- whitish | Kidney, branchial cavity |

Typically, the final hosts of this parasite group are piscivorous birds like herons, pelicans, cormorants and darters, as pictured in the life cycle, figure 22. When the eggs are released via defecation into the water, they need a few days of incubation in their first intermediate host, freshwater molluscs, before they hatch into the next level (cercaria). The cercariae are fork-tailed (furcocercaria) and migrate actively in their water body towards the second intermediate host (fish). The cercaria penetrates the skin, then moves to various organs (eyes, liver, heart, gills, kidney, spleen and brain) of the host fish. When the final host, a piscivorous bird, feeds on the fish, the larvae migrates from the intestinal organs to the pharynx, where it merges into an adult worm. Mostly, they do not cause serious infections on the affected fish, as is the case with many other trematodes species. More than that, in natural conditions, infections



emerge in low levels (Paperna, 1996). But in younger fish, a higher morbidity and also mortality can be linked to heavy infections with large quantities of clinostomid cysts (Florio et al., 2009). Regarding their risk to human health, the species *Clinostomum complanatum* can be accidentally taken up in the human body if the fish are not cooked thoroughly (Florio, 2009). This parasite can then cause laryngopharyngitis (Paperna, 1996). Moreover infections with this parasite group causes economic losses to the fishing industry, compromising the fish's cosmetic appearance severely when it leaves the dead host's body, and thus negatively impacting sales (Florio et al., 2009).

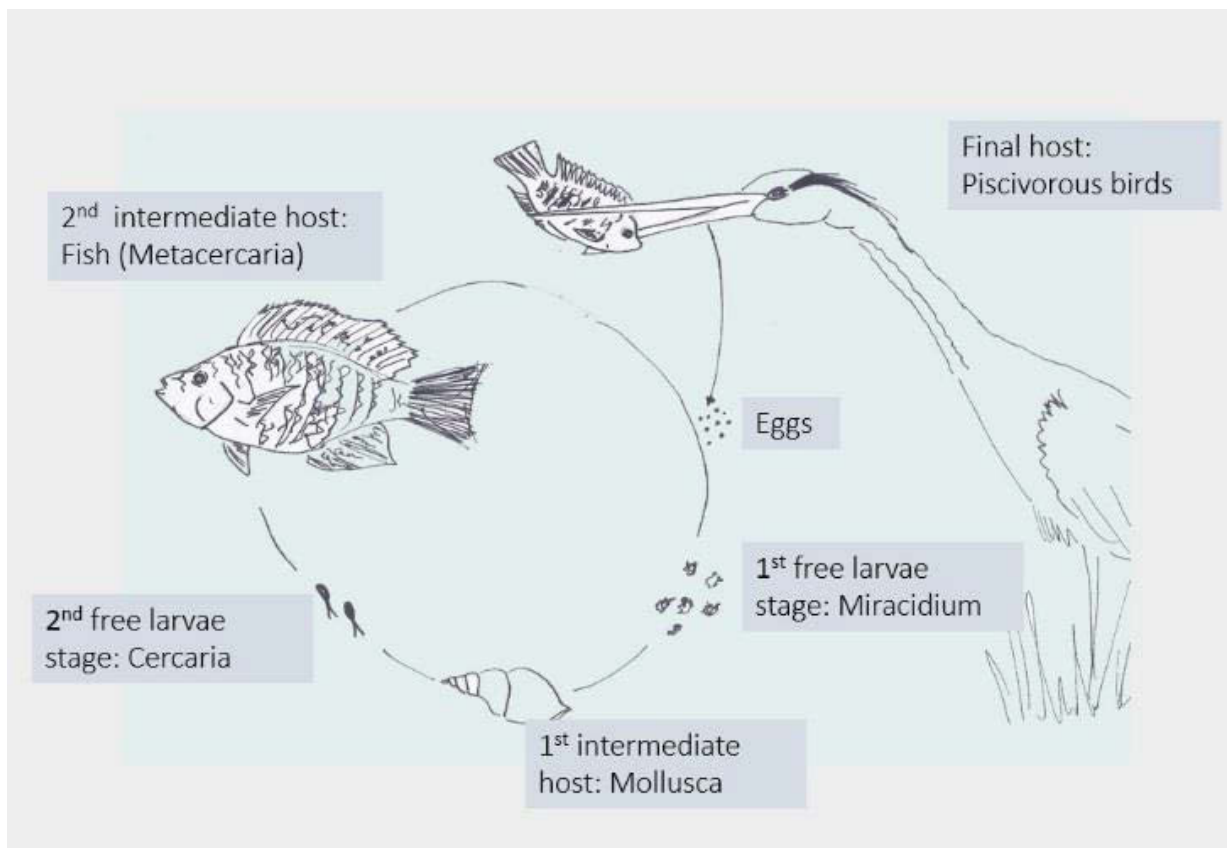


Figure 22: Life cycle of *Clinostomum* sp.



Figure 23: Metacercariae of *Clinostomum* sp.



Figure 24: Metacercariae of *Euclinostomum* sp.

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## 4.5 Nematoda

Phylum: Aschelminthes (Grobber, 1910)

Class: Nematoda (Rudolphi, 1808)

The majority of the 16,000 species of Nematoda are recorded as free-living individuals, but 40% of these species are considered parasites. Furthermore, 8% are parasitic with invertebrate hosts, with the rest infecting vertebrates (Moravec, 1998). Nematodes, both larvae and adults, are typically found in freshwater and marine fish, especially in their intestinal tracts (Dogiel et al., 1961; Hoffman, 1976). Nematodes are considered as generalists and not very host-specific (Poulin, 2006). They are known as roundworms, containing a cylindrical body stretched to a thin, elongated form. A rigid cuticle protects the round body, where organs for attachment are missing (Moravec, 1998). Nematodes have an indirect life cycle, reaching the next host passively by food uptake and undergoing various larval development stages in the intermediate host, see figure 2. For this group, the first intermediate hosts are most frequently crustacean or copepods (Dogiel et al., 1961). These first intermediate hosts swallow the parasites' eggs and enable the parasite to undergo three larval stages within them. When the copepod is eaten by a fish, the second intermediate host, the larvae hatches into the fourth development stage before reaching maternity in its final hosts (piscivorous birds and mammals) (Zander, 1998). Infections of larval nematodes, encased or free, frequently occur with the species of the genera *Contracaecum*, *Amplichaecum* and *Eustrongylides* in Africa, and they are mostly found in the body cavities or digestive systems of their hosts. Further identification on species basis is hardly possible because, in larval stages, the genital system is missing and genitals are required for detailed and accurate identification (Paperna, 1996). Parasites of this group are often matters of public concern, well known as human pathogens (Moravec, 1998).

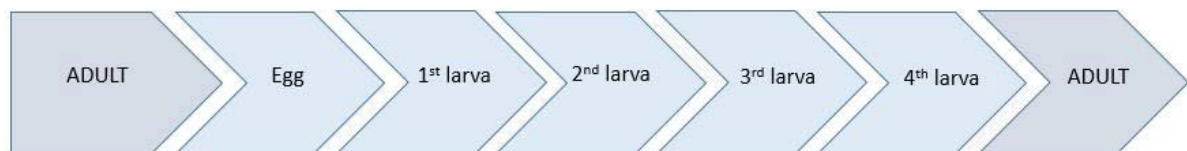


Figure 25: Development stages of nematodes

#### 4.5.1 Anisakidae

Class: Secernentea (Lorenzen, 1981)

Order: Ascararidida (Skyrabin and Shul'ts, 1938)

Family: Anisakidae (Railliet et Henry, 1912)

Genus: *Contracaecum* (Railliet et Henry, 1912)

Species: *Contracaecum* sp.

*Contracaecum* infections are potentially found in all freshwater fish, but occur in higher accumulations in predatory fish all over Africa (Paperna, 1996). The definitive hosts would be piscivorous waterbirds, like pelicans and comorants, shown in figure 26. These birds release the parasite's eggs into the water body via defecation. The eggs hatch after a couple of days, depending on temperature, to a second, free living larval stage. Zooplankton (copepods of the genus *Cyclops*) are the first intermediate host and infects their predators (fish) by food uptake (Paperna, 1996). After the intake of an infected copepod, the third larval stage migrates through the swim bladder until it reaches the pericardium (Paperna, 1996). The larvae may survive, free, in the body cavity or encapsulated in a cyst, reaching a length of 60 mm, as presented in figure 27 (Moravec, 1998; Paperna, 1996). Infected fish do not show serious health restrictions; in contrast, most of them are still in a good health. Infected juvenile fish can be an exception because they are more vulnerable disease. The big larval nematode is capable of moving around in the digestive system, provoking damage in the gut until the juvenile fish stop feeding (Moravec, 1998). When predatory fish are feeding on smaller fish infected with encapsulated larvae, the larvae re-encyst in their new host. The host may be negative impacted by the process of the larvae encapsulating, which provokes fibrous capsules. Nevertheless, these negative impacts on the adult fish health are limited. However, incidental transmission of the larvae of the genus *Contracaecum* to the human body is possible, and it is known as a human pathogen (Moravec, 1998). In particular, the larvae of *Contracaecum multipapillatum* is potentially zoonotic (Florio et al., 2009). Still, they are a larger economic problem because the parasite tries to escape to the surface of the fish after its host's death, causing an unappealing external appearance bad for sales (Florio et al., 2009).

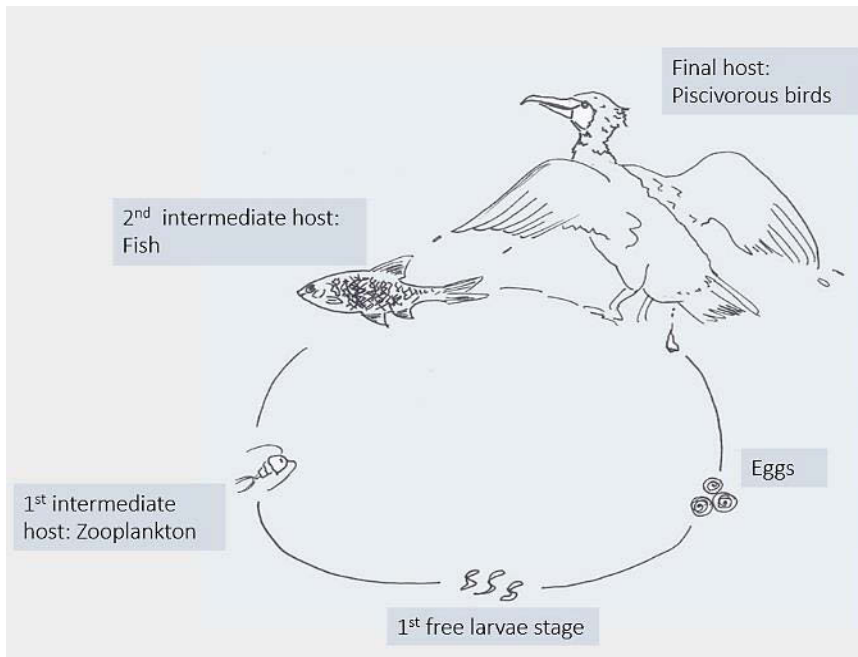


Figure 26: Life cycle of *Contracaecum* sp.



Figure 27: *Contracaecum* sp. larvae

#### 4.5.2 Dioctophymatidae

Class: Nematoda

Order: Trichocephalida (Skryabin and Shul'ts, 1928)

Family: Dioctophymatidae (Railliet, 1915)

Genus: *Eustrongylides* (Jägerskiöld, 1909)

Species: *Eustrongylides* sp.

Larvae of the genus *Eustrongylides* are very similar and are often distinguished from the genus *Dioctophyma*. To identify at the species level, adults with a developed genital system would have been necessary (Moravec, 1998). Detailed knowledge about the life cycle of *Eustrongylides* sp. is still incomplete: the first host is unknown, but assumed to be an Oligochaete (Paperna, 1996). Fish, amphibians and reptiles appear to act as (second) intermediate hosts. *Eustrongylides* sp. larvae seem to have their third or fourth stage of larvae development in fish. Final hosts are fish-eating birds of the orders Ciconiiformes and Pelecaniformes (cormorants, herons and darters) (Moravec, 1998). Frequently, these larvae are found in the abdominal cavity, viscera and tissue of the intermediate hosts, fish. The families Siluridae and Protopteridae often show high infection rates. These predator fish first feed on smaller infected fish. In this case, an accumulation of *Eustrongylides* sp. larvae happens, putting the life cycle of this parasite in a deadlock (Paperna, 1996). These nematode larvae may have

strong impacts on the health of fish. Even very low numbers of encysted larvae may provoke a degeneration of the gonads or total castration of the host, minimizing their reproduction success. Additionally, in cyclid fish, free-living individuals migrate under the skin and muscle where they may invoke inflammation (Paperna, 1996). The same fourth stage larvae (figure 28) that can be found in fish also present the possibility of accidental uptake in the human body, and is therefore a potential health risk to humans (Moravec, 1998). Although the larvae is easily seen, red and about ten cm long, it can also be found encysted in the musculature of fish, white and only one cm long, easily eaten accidentally (Hoffman, 1976).



**Figure 28: *Eustrongylides* sp. larva**

## 4.6 Crustacea

Phylum: Arthropoda (Siebold, 1848)

Class: Crustacea (Lamarck, 1801)

Order: Branchiura (Thorell, 1846)

Branchiura, also called fish lice, is a crustacean parasitic group of around 130 species, all of them living as ectoparasites on variable hosts. Branchiura have a very flat, oval body, covered almost completely by their broad shell, and have distinctive compound eyes. Their mouthparts and antennae have evolved as proboscis, hooks, spines and suckers. When they attach themselves to their host, they drill through the skin of the fish, sucking for nourishment blood, internal fluids and sometimes mucus and skin. Fish lice are perfectly adapted for a parasitic lifestyle. Nevertheless, Branchiura must leave the host for various reasons, like reproduction (Waggoner, 2006).

### 4.6.1 Argulidae

Class: Crustacea

Order: Branchiura (Thorell, 1864)

Family: Argulidae (Leach, 1819)

Genus: *Dolops* (Audouin, 1837)

Species: *Dolops ranarum* (Stuhlmann, 1891)

In Africa, only one species of *Dolops* has been identified: *Dolops ranarum* (figure 29). This species is often distinguished from *Argulus sp.*, which belongs to the same family Argulidae. The genus *Argulus* possess the same head appendages and dorso-ventrally flattened and shaped carapace that *Dolops ranarum* has. In contrast, members of the genus *Dolops* have a hook instead of a sucker on their second maxilla. The three to eight mm long ectoparasite prefers smooth-skinned fish like the families Siluridae or Protopteridae. Nevertheless, this species is also capable of living on the mucosal parts of fish with scales, like cichlids, and is therefore considered as generalist. Moreover, *Dolops ranarum* is very adaptive regarding water quality and the quantity of dissolved oxygen because it possesses hemoglobin. This taxon is able to survive even on mud aestivating fish (Abowei & Ezekiel, 2011b). Typical for the fish lice of the genus *Dolops* is their direct life-cycles. *Dolops ranarum* is only able to survive roughly 15 days as a free-living form without a host. *Dolops ranarum* has to leave its

host for several reasons, like reproduction and egg release. The eggs are deposited in the water substrate, where they hatch after 25-35 days. The juveniles of *Dolops* already have their adult form and do not have the nauplii status. Their annual cycle of reproduction in the tropics is unknown, but it seems to be restricted to a particular season (October), when the lowest infection rate on fish occurs (Abowei & Ezekiel, 2011b). Infections with *Dolops ranarum* are potentially pathogenic in fish farms, where they may cause very strong infections. In natural conditions like lakes, the infections occur in lower rates and their effects on their hosts are less harmful. When the parasite starts migrating, it may cause inflammation and hemorrhages through damage to the epithelial layer of the skin. This can lead to permanent damage of the fish's skin and degradation of the mucous cells, causing oedema at the epithelium and acantholysis. The hosts may then become vulnerable to colonization by fungi and bacteria at their open wounds, influencing the fish's appetites negatively and causing growth declines (Paperna, 1996).



**Figure 29: *Dolops ranarum***

## 5 Results

In this study, four commercially important fish species *Oreochromis niloticus baringoensis*, *Barbus intermedius australis*, *Clarias gariepinus* and *Protopterus aethiopicus* of Lake Baringo were investigated for parasites. We carried out parasitic examinations for ecto- and endoparasites in 101 fish specimens. Subsequent necropsy was performed in detail for the endoparasites. Ten different parasite groups of ten different families were discovered. Only three were freely transmitted ectoparasites, the rest were endoparasites with complex indirect life cycles. Standard measurements (prevalence, mean intensity, abundance, dominance) were calculated for each fish and parasite species. Additionally, species diversity was determined on the component community level by using biodiversity indices. Finally, ecological characteristics such as their living forms (ecto-/endoparasites), life cycles (1<sup>st</sup> and 2<sup>nd</sup> intermediate and final host), status (autogenic or allogenic), and type (generalist or specialist) are classified for each species based on literature review.

### 5.1 Standard analyses

2598 parasite specimens of ten different taxa were found in the 101 fish individuals. 33 specimens of *Oreochromis niloticus baringoensis* were analysed and we concluded that this fish species harbours the highest mean infection rate, with 97 parasites per fish, and the greatest diversity with seven different taxa found (table four). For all that reasons, this fish species is expressing the highest values of the Simpson (0,81) and Berger-Parker (0,89) indices. But regarding the Shannon diversity index, *Clarias gariepinus*, with its sampling size of 16 individuals, has the highest value. Also, *C. gariepinus* showed the highest prevalence value of 100%, explaining that every examined catfish was infected with parasites. The confidence interval was small (0,81-1), allowing us to provide more precise estimates for this fish species (figure 30): *Barbus intermedius australis*, with 40 investigated specimens, is already showing moderate to weak mean infection rates and diversity values. In general, *Protopterus aethiopicus* expresses very weak infection rates, with only two parasites in all of the 12 specimens examined. The confidence interval of the fish species *P. aethiopicus* is wide, lowering the precision of our estimates of the real value of prevalence, also overlapping with *B. intermedius australis*. Finally, it has to be noted that the three fish



species, *Clarias gariepinus*, *Barbus intermedius australis* and *Protopterus aethiopicus*, were dominated by the same parasite taxon, nematoda, in contrast to the infection of *Oreochromis niloticus baringoensis* with cestoda.

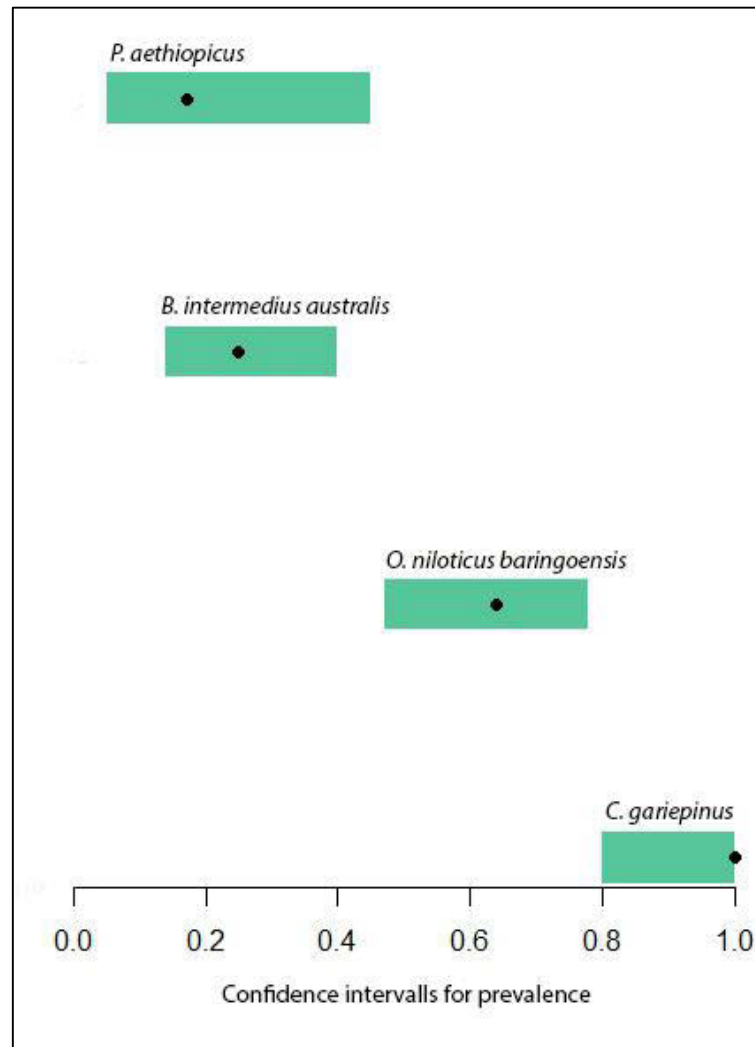


Figure 30: Prevalences (black points) and confidence intervals of all four fish species of Lake Baringo

**Table 4: Sampling size (N), mean length and length range of sampled fish species, as well as the number of infected fish, the total number of parasites, infection intensity (mean & range), resulting total prevalence, confidence intervals, parasite taxa diversity and the dominant parasite taxon per fish species with the corresponding Shannon Wiener Index (H), Berger-Parker index (BP), Simpson index (D) and maximum infracommunity richness (max. ICR)**

| Species                         | N  | mean length & range | Number of infected fish | Total number of parasites | Mean infection & intensity range | Total prevalence of parasites [%] | Confidence interval of prevalence | Parasite Richness | Dominant parasite taxon | H    | D    | BP   | Max. ICR |
|---------------------------------|----|---------------------|-------------------------|---------------------------|----------------------------------|-----------------------------------|-----------------------------------|-------------------|-------------------------|------|------|------|----------|
| <i>O. niloticus</i>             | 33 | 18 (12-24)          | 21                      | 2137                      | 97 (11-501)                      | 64                                | 0.47-0.78                         | 7                 | Cestoda                 | 1.43 | 0.81 | 0.89 | 4        |
| <i>O. baringoensis</i>          | 33 | 18 (12-24)          | 21                      | 2137                      | 97 (11-501)                      | 64                                | 0.47-0.78                         | 7                 | Cestoda                 | 1.43 | 0.81 | 0.89 | 4        |
| <i>B. intermedius australis</i> | 40 | 18 (11-32)          | 10                      | 84                        | 8 (1-24)                         | 25                                | 0.14-0.4                          | 3                 | Nematoda                | 1.35 | 0.29 | 0.36 | 3        |
| <i>C. gariepinus</i>            | 16 | 38 (32-55)          | 16                      | 375                       | 23 (8-49)                        | 100                               | 0.81-1                            | 4                 | Nematoda                | 1.56 | 0.41 | 0.44 | 2        |
| <i>P. aethiopicus</i>           | 12 | 63 (55-70)          | 2                       | 2                         | 1 (1-2)                          | 17                                | 0.05-0.45                         | 2                 | Nematoda                | 0.19 | 0.21 | 0.27 | 1        |

## 5.2 Parasite species analyses

The focus of this study was on helminths; nevertheless, examinations of all four fish species were carried out for ectoparasites. In total, ten different taxonomic groups of parasites were recorded: one group of Protozoa (*Myxobolus sp.*) and nine groups of metazoan parasites. Three of them were ectoparasites and free-living transmitted; they belonged to the following classes: Myxosporea (*Myxobolus sp.*), Monogenea (*Dactylogyrus sp.*) and Crustacea (*Dolops ranarum*). All of them represented allogenic parasites with direct life cycles, not involving intermediate hosts and their maturation occurring in fish. All ectoparasites were found in very sporadic, sometimes even stray findings. The remaining seven groups are endoparasitic helminths with autogenic, indirect life cycles, and they belonged to the classes of Trematoda (Digenea), Cestoda and Nematoda, listed in table five with their hosts and the organs they infect. It is important to note that all of them have the same group of final hosts: water birds. The first intermediate hosts vary between molluscs, zooplankton and oligochaetes. Most of them, immature parasites, are defined as generalists on the basis of a literature review on their last identified taxonomic levels. Only the gill parasites of the genus *Dactylogyrus* are considered as specialists, like most other monogenean parasites.

Table 5: Parasite taxa diversity, the corresponding location on fish, life cycle (first intermediate & final host) and their status as autogenic (Au) or allogenic (Al), and as type generalist (G) or specialist (S)

| Parasite                   | Location in the fish host | Life cycle | 1st intermediate host     | Final host | Status | Type | Reference               |
|----------------------------|---------------------------|------------|---------------------------|------------|--------|------|-------------------------|
| <b>Protozoa</b>            |                           |            |                           |            |        |      |                         |
| <i>Myxobolus</i> sp.       | Gills                     | ID         | Oligochaeta               | Fish       | Au     | G    | El-Mansy & Molnar, 1997 |
| <b>Monogenea</b>           |                           |            |                           |            |        |      |                         |
| <i>Dactylogyrus</i> sp.    | Gills                     | D          | Fish                      | Fish       | Au     | S    | Paperna, 1996           |
| <b>Trematoda</b>           |                           |            |                           |            |        |      |                         |
| Metacercariae              | Gills                     | ID         | Mollusca                  | Waterbird  | Al     | G    | Paperna, 1996           |
| <i>Diplostomum</i> sp.     | Cranial cavity            | ID         | Mollusca                  | Waterbird  | Al     | G    | Paperna, 1996           |
| <b>Digenea (trematoda)</b> |                           |            |                           |            |        |      |                         |
| <i>Clinostomum</i> sp.     | Gill cavity               | ID         | Mollusca                  | Waterbird  | Al     | G    | Paperna, 1996           |
| <i>Euclinostomum</i> sp.   | Kidney                    | ID         | Mollusca                  | Waterbird  | Al     | G    | Florio et al., 2009     |
| <b>Cestoda</b>             |                           |            |                           |            |        |      |                         |
| larvae                     | Intestine wall            | ID         | Zooplankton & Oligochaeta | Waterbird  | Al     | Un   | Paperna, 1996           |
| <b>Nematoda</b>            |                           |            |                           |            |        |      |                         |
| <i>Contracaecum</i> sp.    | Body cavity               | ID         | Zooplankton               | Waterbird  | Al     | G    | Paperna, 1996           |
| <i>Eustrongylides</i> sp.  | Body cavity & musculature | ID         | Oligochaeta               | Waterbird  | Al     | G    | Moravec, 1998           |
| <b>Crustacea</b>           |                           |            |                           |            |        |      |                         |
| <i>Dolops ranarum</i>      | Skin                      | D          | Fish                      | Waterbird  | Au     | G    | Abowei & Ezekiel, 2011b |

### 5.2.1 Ectoparasites

*Myxobolus sp.* and *Dactylogyrus sp.* infected the gills of the fish host, and only *Dolops ranarum* was found on the skin of *Clarius gariepinus*. The fish species *B. intermedius australis* were infected by two different groups of ectoparasites, with low prevalence values (table six).

**Table 6: Prevalence (P), mean intensity (Mi) and abundance (Ab) of ectparasites per fish species (na = non available)**

| Parasite                | <i>O. niloticus baringoensis</i> | <i>B. intermedius australis</i> | <i>C. gariepinus</i> | <i>P. aethiopicus</i> |
|-------------------------|----------------------------------|---------------------------------|----------------------|-----------------------|
| <i>Myxobolus sp.</i>    |                                  |                                 |                      |                       |
| <b>P [%]</b>            |                                  | 2.5                             |                      |                       |
| <b>Mi</b>               | na                               | 1                               | na                   | na                    |
| <b>Ab</b>               |                                  | 0.03                            |                      |                       |
| <i>Dactylogyrus sp.</i> |                                  |                                 |                      |                       |
| <b>P [%]</b>            | 2.5                              | 3                               |                      |                       |
| <b>Mi</b>               | 1                                | 1                               | na                   | na                    |
| <b>Ab</b>               | 0.03                             | 0.03                            |                      |                       |
| <i>Dolops ranarum</i>   |                                  |                                 |                      |                       |
| <b>P [%]</b>            |                                  |                                 | 6.25                 |                       |
| <b>Mi</b>               | na                               | na                              | 1                    | na                    |
| <b>Ab</b>               |                                  |                                 | 0.06                 |                       |

### 5.2.2 Endoparasites

Regarding the helminth community distributed over the four species, *Contracaecum sp* of class Nematoda was the most widely spread, with high prevalence values, existing in all of the surveyed fish species. The Nematoda *Eustrongylides sp.* and *Euclinostomum sp.* were found in two fish species, both in *Oreochromis niloticus baringoensis*. Nematoda larvae, as well as the metacercariae of the Digenea *Diplostomum sp.*, *Clinostomum sp.*, and the cestoda larvae were limited to a single fish species (table seven).

**Table 7: Prevalence (P), mean intensity (Mi) and abundance (Ab) of endoparasites per fish species (na= non available)**

| Parasite                  | <i>O. niloticus<br/>baringoensis</i> | <i>B. intermedius<br/>australis</i> | <i>C. gariepinus</i> | <i>P. aethiopicus</i> |
|---------------------------|--------------------------------------|-------------------------------------|----------------------|-----------------------|
| <i>Diplostomum sp.</i>    |                                      |                                     |                      |                       |
| <b>P [%]</b>              |                                      |                                     | 6.25                 |                       |
| <b>Mi</b>                 | na                                   | na                                  | 1                    | na                    |
| <b>Ab</b>                 |                                      |                                     | 0.06                 |                       |
| <i>Clinostomum sp.</i>    |                                      |                                     |                      |                       |
| <b>P [%]</b>              | 12.12                                |                                     |                      |                       |
| <b>Mi</b>                 | 9                                    | na                                  | na                   | na                    |
| <b>Ab</b>                 | 1.09                                 |                                     |                      |                       |
| <i>Euclinostomum sp.</i>  |                                      |                                     |                      |                       |
| <b>P [%]</b>              | 3.03                                 |                                     | 18.75                |                       |
| <b>Mi</b>                 | 1                                    | na                                  | 1.33                 | na                    |
| <b>Ab</b>                 | 0.03                                 |                                     | 0.25                 |                       |
| Cestoda larvae            |                                      |                                     |                      |                       |
| <b>P [%]</b>              | 54.55                                |                                     |                      |                       |
| <b>Mi</b>                 | 114.44                               | na                                  | na                   | na                    |
| <b>Ab</b>                 | 62.42                                |                                     |                      |                       |
| <i>Contracaecum sp.</i>   |                                      |                                     |                      |                       |
| <b>P [%]</b>              | 27.27                                | 25                                  | 100                  | 8.33                  |
| <b>Mi</b>                 | 3                                    | 2.8                                 | 23.6                 | 1                     |
| <b>Ab</b>                 | 0.27                                 | 0.7                                 | 23.06                | 0.08                  |
| <i>Eustrongylides sp.</i> |                                      |                                     |                      |                       |
| <b>P [%]</b>              | 3.03                                 |                                     |                      | 8.33                  |
| <b>Mi</b>                 | 1                                    | na                                  | na                   | 1                     |
| <b>Ab</b>                 | 0.03                                 |                                     |                      | 0.08                  |
| Trematoda metacercariae   |                                      |                                     |                      |                       |
| <b>P [%]</b>              | 9.09                                 |                                     | 0                    |                       |
| <b>MI</b>                 | 9.67                                 | na                                  | 0                    | na                    |
| <b>Ab</b>                 | 0.88                                 |                                     | 0                    |                       |

### 5.3 Component community level

In this chapter, all discovered parasite species of one host population are demonstrated, as well as prevalence, mean intensity, abundance and dominance.

#### 5.3.1 *O. niloticus baringoensis*

Seven different groups of parasites were found in the fish species *O. niloticus baringoensis*, five of these were helminths. The unidentified cestoda larvae was the most abundant parasite (96%), restricted to the intestine wall of *O. niloticus baringoensis*. The mean intensity was higher than 114 parasites per fish. Two species of nematodes were found: Larvae of *Contraecaecum sp.* and *Eustrongylides sp.* *Contraecaecum sp.* was the second most frequent parasite species. The nematode *Eustrongylides sp.* and the digenean trematode *Euclinostomum sp.*, had both low prevalence, mean intensity and abundance values (table eight).

**Table 8: Prevalence (P), mean intensity  $\pm$  standard deviation (Mi $\pm$ SD), abundance (A), and dominance (d), as well as information about the life cycle (ecto. - or endoparasite) of parasites of *O. niloticus baringoensis***

| Parasite group | Taxon                                       | Ecto. | Endo. | P [%] | Mi $\pm$ SD     | Ab    | d [%] |
|----------------|---|-------|-------|-------|-----------------|-------|-------|
| Monogenea      | <i>Dactylogyrus sp.</i>                     | x     |       | 3.3   | 1 $\pm$ 0.03    | 0.03  | 0     |
| Trematoda      | Metacercariae                               | x     |       | 9.09  | 9.67 $\pm$ 0.75 | 0.88  | 1     |
| Digenea        | <i>Clinostomum sp.</i><br>(metacercariae)   |       | x     | 12.12 | 9 $\pm$ 0.75    | 1.09  | 2     |
| Digenea        | <i>Euclinostomum sp.</i><br>(metacercariae) |       | x     | 3.03  | 1 $\pm$ 0.03    | 0.03  | 0     |
| Cestoda        | larvae                                      |       | x     | 54.55 | 114.44 $\pm$ 44 | 62.42 | 96    |
| Nematoda       | <i>Contraecaecum sp.</i><br>(larvae)        |       | x     | 27.27 | 3 $\pm$ 0.21    | 0.27  | 0     |
| Nematoda       | <i>Eustrongylides sp.</i><br>(larvae)       |       | x     | 3.03  | 1 $\pm$ 0.03    | 0.03  | 0     |

### 5.3.2 *B. intermedius australis*

With four different species, *B. intermedius australis* had a moderate species richness value. No remarkable differences were observed between the prevalence values of the ectoparasites *Myxobolus sp.* and *Dactylogyrus*. The dominant taxonomic group was a nematode, *Contraecaecum sp.*, with a maximum prevalence of 25% and an abundance of 0.7, with more than two parasites found per specimen (table nine).

**Table 9: Prevalence (P), mean intensity  $\pm$  standard deviation (Mi $\pm$ SD), abundance (A), and dominance (d), as well as information about the life cycle (ecto. - or endoparasite) of parasites of *B. intermedius australis***

| Parasite group | Taxon                                | Ecto. | Endo. | P [%] | Mi $\pm$ SD     | Ab   | d [%] |
|----------------|--------------------------------------|-------|-------|-------|-----------------|------|-------|
| Protozoa       | <i>Myxobolus sp.</i>                 | x     |       | 2.5   | 1 $\pm$ 0.02    | 0.03 | 3     |
| Monogenea      | <i>Dactylogyrus sp.</i>              | x     |       | 2.5   | 1 $\pm$ 0.02    | 0.03 | 3     |
| Nematoda       | <i>Contraecaecum sp.</i><br>(larvae) |       | x     | 25    | 2.80 $\pm$ 0.78 | 0.7  | 93    |

### 5.3.3 *C. gariepinus*

*C. gariepinus* was infected by one ectoparasite, *Dolops ranarum*, and four endoparasites. The taxonomic group of Nematoda had the highest prevalence value and dominance with *Contraecaecum sp.* larvae, followed, with a substantial difference, by *Euclinostomum sp.*, *Dolops ranarum* and *Diplostomum sp.* These three parasite groups were only detected in low numbers, representing relatively low mean intensity and abundance values (table ten).



**Table 10: Prevalence (P), mean intensity  $\pm$  standard deviation (Mi $\pm$ SD), abundance (A), and dominance (d), as well as information about the life cycle (ecto. - or endoparasite) of parasites of *C. gariepinus***

| Parasite group | Taxon                                       | Ecto. | Endo. | P [%] | Mi $\pm$ SD      | Ab   | d [%] |
|----------------|---|-------|-------|-------|------------------|------|-------|
| Trematoda      | <i>Diplostomum sp.</i><br>(metacercariae)   |       | x     | 6.25  | 1 $\pm$ 0.06     | 0.03 | 3     |
| Digenea        | <i>Euclinostomum sp.</i><br>(metacercariae) |       | x     | 18.75 | 1.33 $\pm$ 0.14  | 0.03 | 3     |
| Nematoda       | <i>Contraecum sp.</i><br>(larvae)           |       | x     | 100   | 23.06 $\pm$ 3.31 | 0.7  | 93    |
| Crustacea      | <i>Dolops ranarum</i>                       | x     |       | 6.25  | 1 $\pm$ 0.06     | 0.06 | 0     |

#### 5.3.4 *P. aethiopicus*

In the fish species *P. aethiopicus*, no ectoparasites were found. The helminth fauna was poor too, with only sporadic findings of *Eustrongylides sp.* and *Contraecum sp.* larvae (table eleven).

**Table 11: Prevalence (P), mean intensity  $\pm$  standard deviation (Mi $\pm$ SD), abundance (A), and dominance (d), as well as information about the life cycle (ecto. - or endoparasite) of parasites of *P. aethiopicus***

| Parasite group | Taxon                                 | Ecto. | Endo. | P [%] | Mi $\pm$ SD  | Ab   | d [%] |
|----------------|---------------------------------------|-------|-------|-------|--------------|------|-------|
| Nematoda       | <i>Contraecum sp.</i><br>(larvae)     |       | x     | 8.33  | 1 $\pm$ 0.08 | 0.08 | 50    |
| Nematoda       | <i>Eustrongylides sp.</i><br>(larvae) |       | x     | 8.33  | 1 $\pm$ 0.08 | 0.08 | 50    |

#### 5.4 Relation between fish length and parasite abundance

The correlation between fish length and the abundance of parasitic infections derived from the two most abundant parasite groups, larvae of *Contracaecum sp.* in *C. gariepinus* (simple linear regression:  $R^2= 0.135$ ,  $p= 0.162$ , figure 31) and the unidentified larval cestodes in *O. niloticus baringoensis* (simple linear regression:  $R^2= 0.114$ ,  $p= 0.186$ , figure 32) was negative, low and non-significant.

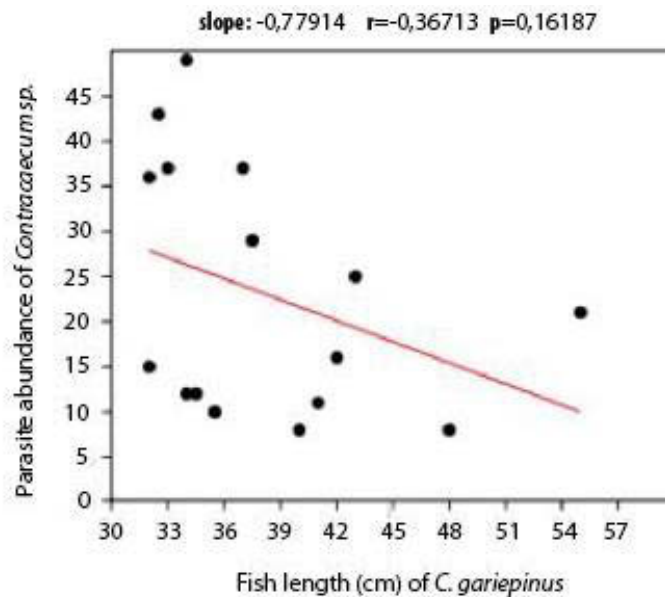


Figure 31: Correlation between the abundance of the parasite species *Contracaecum sp.* and the fish size of the corresponding host *C. gariepinus*

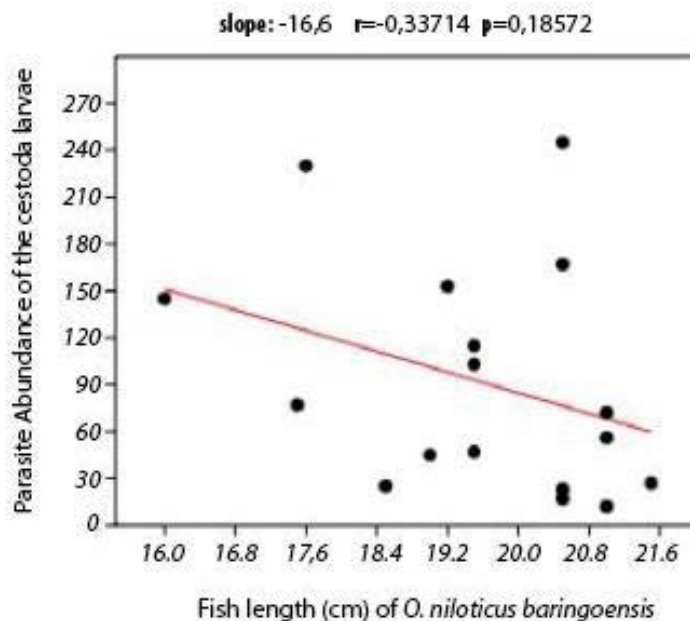


Figure 32: Correlation between the abundance of the larval cestodes and the fish size of the corresponding host *O. niloticus baringoensis*

## 5.5 Dispersion spectrum

Two different models for the distribution of infection intensity, Poisson and negative binomial distribution, were compared. The positive binomial distribution was excluded from model selection due to lack of convergence in parameter estimation, which indicates a poor fit of the model with the original data. At the highest value of 0.9 for the model, the negative binomial distribution was the best fitting distribution, with a chance of 99 %, for both parasite groups (*Contracaecum sp.* in *C. gariepinus* and cestoda larvae in *O. niloticus baringoensis*) in regards to the Akaike weights (table twelve).

**Table 12: Summary of two models for the distribution of infections intensity of the parasite *Contracaecum sp.* in *C. gariepinus* and the unidentified cestoda larvae in *O. niloticus baringoensis*. Includes the total number of parameters (K),  $\Delta_i$  values for AICc, followed by the Akaike weights ( $\omega_i$ ) based on the AICc models.**

| Model                          | K | log(L)  | AICc   | $\Delta_i$ | $\omega_i$ |
|--------------------------------|---|---------|--------|------------|------------|
| <b><i>Contracaecum sp.</i></b> |   |         |        |            |            |
| Poisson distribution           | 1 | -393.93 | 199.25 | 69.62      | <0,001     |
| Neg. binomial distribution     | 2 | -249.42 | 129.63 | 0          | >0,999     |
| <b>Cestoda larvae</b>          |   |         |        |            |            |
| Poisson distribution           | 1 | -116.87 | 60.57  | 25.36      | <0,001     |
| Neg. binomial distribution     | 2 | -61.62  | 35.21  | 0          | >0,999     |

## 6 Discussion

### 6.1 Parasite richness per fish species

In general, freshwater fish are infected by a restricted helminth parasite fauna, while birds and mammals harbor a more diverse parasite community (Esch & Fernandez, 1993). Numerous theories explain the limited parasite fauna of fish. First, the diet composition of fish is restricted, automatically limiting their risk to infection (Dogiel et al., 1961; Esch & Fernandez, 1933). Additionally, their digestive systems are distinctively simpler than that of birds and mammals, providing fewer possible niches for parasitic infection. Finally, fish are ectotherms so less energy is required to maintain good health, which is why fish as intermediate hosts may have low infection rates (Esch & Fernandez, 1993). Overall, only ten different parasite groups, which are listed in chapter 5.2, were recorded in four different fish species, which fits to the assumption above. Out of them, seven metazoan parasites appear to mature in piscivorous water birds (Paperna, 1996). Lake Baringo has an extraordinarily high biodiversity of birds, and thus a large number of possible definitive hosts for these parasites (Britton et al., 2008), (Paperna, 1996). *O. niloticus baringoensis* had the highest parasite diversity per fish species, with seven metazoan parasite groups, and was followed by *C. gariepinus* with four parasite groups. The taxonomic parasite richness of both fish species reflects similar results when compared with other parasite diversity research carried out in Kenya, Uganda and Ethiopia, (Akoll et al., 2012; Otachi et al., 2014; Tadesse, 2009;). This corresponds to the assumption that identical climatic conditions may synchronize the transmission of parasites, and their population size (Hudson et al., 2006). The only exception is Lake Thana, where the species richness is lower; only three metazoan parasite groups were found in *O. niloticus baringoensis* and two species were found in *C. gariepinus* (Yimer & Enyew, 2003). In contrast, the species richness of *B. intermedius australis* included one protozoan and two metazoan parasite groups. All of these parasite species are common parasites in Africa and known to infect species of the genus *Barbus* (Gulelat et al., 2013). The lowest diversity was observed in *P. aethiopicus*, due to the sporadic findings of only two nematode species: *Contracaecum sp.* and *Eustrongylides sp.* Even though Paperna (1996) had already described the possible occurrence of these two species in *P. aethiopicus*, there is no scientific data or detailed information about parasites of this fish species.

## 6.2 Parasite species composition and distribution

In this chapter, the parasite species composition found in fish species, as listed in the results (chapter 5.2) and the distribution of parasites in other African lakes will be compared to the findings of this study.

### Crustaceans and Monogeneans

Ectoparasitological investigation was performed, but the results are untrustworthy, as explained in chapter 3.4.2. This may explain the low appearance and intensity of ectoparasitic species found in this study. In general, ectoparasites are more successful in fish farms, where they spread easily to multiple hosts because of the overcrowding. Ectoparasites develop, transmit and reproduce faster in aquaculture than in natural conditions (Reichenbach-Klinke, 1975). In natural conditions, where there is no fish overcrowding, parasites live in equilibrium with their hosts, perhaps explaining why infection rates of these parasite groups may be low in Lake Baringo (Zander, 1998).

The Monogenea *Dactylogyrus sp.* is a typical freshwater fish parasite highly host-specific and located on the gills of various African fish families. *Dactylogyrus sp.* was recorded as an ectoparasite in low intensity on the fish species *O. niloticus baringoensis* and *B. intermedius australis*. In contrast, in Lake Naivasha, *Dactylogyrus sp.* was highly prevalent on *Barbus paludinosus* (83.6%) and *Oreochromis leucostictus* (51.8%) (Otachi et al., 2014).

The crustacean parasite *Dolops ranarum* is a generalist and tolerant regarding its final host. It infects many different fish species and is widely distributed across Africa. Still, infections are more likely in smooth-skinned fish like *C. gariepinus* (Paperna, 1996). In this study, *D. ranarum* was found once on the skin of *C. gariepinus*, reflecting the records from Lake Tana, Ethiopia, where there was only a sporadic appearance of this species (Yimer & Enyew, 2003). On the contrary, in Lake Awassa, *C. gariepinus* has a prevalence value of 100% (Tadesse, 2009).

### Cestodes

Species identification of the cestoda larvae, found encysted in the gut wall of *O. niloticus baringoensis*, is still ongoing, making a comparison with other datasets not possible at this time.

## Digenean trematodes

*Diplostomum sp.* was not detected in the lens of fish in Lake Baringo, supporting other scientists' claims, that the parasite *Diplostomum spathaceum* that is specific to infecting lens does not exist in African water systems due to inappropriate habitat conditions for their first intermediate hosts (Zokhov et al., 2007). In Africa, *Diplostomum spp.* infestations are frequently found in the anterior or vitreous humor, where it was also recovered in this research (Florio et al., 2009). Paperna (1996) and Zhokhov et al. (2007) identified trematodes metacercariae in the brain tissue of the African siluriform fish to be *Diplostomum tregenna*. In various water reservoirs in Kenya used for fish farms, Diplostomatid metacercariae were found with a prevalence rate of 50% (Florio et al., 2009). At the Mindu Dam, Tanzania, *Diplostomum mashonense* was also found to have a high prevalence of p=83.3% (Mukama, 2008). In Ethiopia, surveys in Lake Awassa and Babogaya found *Diplostomum sp.* to have an infection rate of 100% within the cranial cavity of *C. gariepinus* (Tadesse, 2009).

Clinostomatid metacercariae are frequently found in Africa, as their definitive hosts are migrating piscivorous birds (Paperna, 1996; Yimer and Enyew, 2003). Infections by these digenetic trematodes are known to occur in cichlid and siluriform fish, and sometimes in the species of *Barbus* (Paperna, 1996). In this research, infections of metacercariae of Clinostomatidae occurred in the gill cavity of the cichlid fish *O. niloticus baringoensis* (*Clinostomum sp.* & *Euclinostomum sp.*) and on the kidney of *Clarius gariepinus* (*Euclinostomum sp.*). *Clinostomum spp.* may be found inside the fish's body cavities or on their skin (Yimer & Enyew, 2003). In Lake Babogaya (p=34.3) and Lake Awassa (p=50) in Ethiopia, the intensity of *Clinostomum sp.* among *O. niloticus* was respectively high (Florio et al., 2009). Moreover, in Lake Tana, the reported prevalence rate was 62.2% for *Clinostomum sp.* in *O. niloticus* and *Clinostomum spp.* was found to infect fish in both, their branchial and pericardial cavities, which could more strongly affect the fish's health (Yimer & Enyew, 2003). In the current survey, *Clinostomum sp.* were only recovered in branchial cavities at a prevalence rate of 12.1%. *Euclinostomum sp.* was recorded in the branchial cavity (p=2.3%) and kidney (p=4.6%) of *O. niloticus*. In water reservoirs in Kenya, used for fish farming, Clinostomid metacercariae among *O. niloticus* were found at low intensities (p=1.8%) (Florio et al., 2009). Paperna (1996) describes the seasonal appearance of infections with *Clinostomum* in *O. niloticus* at the Nuungua Dam in Ghana. Infection rates and prevalence values are at their highest during the months of September-

October, the end of rain season. Infection rates declined between December to May, the dry season and when the number of snails are lowest (Paperna, 1996). In this survey, all sampling work was carried out at the end of dry season in March-April, possibly explaining the low intensity of Clinostomatidae in Lake Baringo. However, Aloo (2002) suggested that parasite life cycles in the tropics are more less affected by seasonal changes because intermediate hosts can be found permanently in tropical climates. More studies at Lake Baringo over a longer timeframe are recommended to learn more about the possible seasonal associations with parasite life cycles in the tropics. Interestingly enough, at Lake Naivasha in the most recent fish parasite survey of East Africa, Clinostomatidae metacercariae were absent during dry season (Otachi et al., 2014).

### **Nematodes**

*Contracaecum* larvae are generalists concerning their choice of intermediate hosts. They infect a wide range of fish species and occur all the way across Europe to East Africa, dispersed by the migration routes of their final hosts, piscivorous birds (Paperna, 1996). Zhokhov et al. (2007) defined *Contracaecum spp.* as a common endoparasite, especially for *C. gariepinus* and *O. niloticus*. Though *Contracaecum sp.* is a highly prevalent fish parasite, they are sensitive to water pollution because of their first intermediate host copepod's vulnerability to water pollution (Madanire-Moyo & Barson, 2010). In Lake Tana, Ethiopia, *Contracaecum sp.* was infecting *O. niloticus* at a high prevalence rate of 59.8%, at 51.8% in Lake Naivasha, and 48.6% at Lake Awassa (Otachi et al., 2014; Tadesse, 2009; Yimer ad Enyew, 2003). A prior investigation, Paperna (1980), described a 70% infection rate for *O. niloticus*, with a mean intensity of five worms per fish in Lake Baringo. In this study, the prevalence of *Contracaecum sp.* in *O. niloticus baringoensis* was less than 27.7%, with a mean intensity of three parasites per fish. This prevalence rate is close to that found in the study of Malvestuto & Ogambo-Ongoma (1978) in Lake George, Uganda, where 30% of *O. niloticus* were reported as infected, with a mean intensity of one worm per fish (Florio et al., 2009). In this research, larvae of *Contracaecum sp.* were most prevalent (100%) in *C. gariepinus*, with a mean intensity of 23 parasites per fish. Moreover, many African catfish are showing high prevalence rates of *Contracaecum*; for example, 41.5% in Lake Tana and 75% in Lake Awassa, Ethiopia (Tadesse, 2009; Yimer & Enyew, 2003). This study had findings similar to those in Lake Babogaya, Ethiopia,

where 98.5% of African catfish were infected with *Contracaecum sp.*, with a mean intensity of 21 parasites per fish (Tadesse, 2009).

Various *Barbus* species (*B. acutirostris*, *B. tsanensis* and *B. brevicephalus*) have been examined in Lake Tana, all of them were infected of *Contracaecum sp.* in low prevalence rates at 24.6%, 9.4% and 12.8%, respectively (Yimer & Enyew, 2003). Similar low prevalence rates at 16.4% apply to *B. intermedius*, caught at Koka reservoir, Ethiopia (Gulelat et al., 2013). These results are close to the rates of *Barbus intermedius australis* found at Lake Baringo in this study: 25% for *Contracaecum sp.* While low, these prevalence rates support the prediction that *Contracaecum sp.* infects the most diverse number of fish species in Lake Baringo, as they do in Lake Tana and Ziway in Ethiopia and Lake Naivasha in Kenya (Otachi et al., 2014; Yimer & Enyew, 2003; Yimer, 2000).

In Lake Tana, Ethiopia, a single *Eustrongylides sp.* larvae was found in the body cavity of the fish species *Barbus acutirostris* (Yimer & Enyew, 2003). Paperna (1996) described the occurrence and accumulation of *Eustrongylides* larvae in predator fish at higher trophic levels, for example in large catfish and lungfish. These larvae may be normally found in cichlid fish, but after the cichlid's ingestion by predatory fish, they re-encyst in the new host. Larger fish are usually not the prey of fish-eating birds. The larger the fish, the higher the presence and accumulation of *Eustrongylides* larvae. For the parasite, transmission to predatory fish means a deadlock in its life cycle, as it is not able to reach sexual maturity. In the prevalent study, larval forms of *Eustrongylides sp.* were found in the cichlid fish species *O. niloticus baringoensis*, as well as in the predatory fish *P. aethiopicus*. In Lake Victoria, heavy infections of *Clarias mossambicus* and *Protopterus aethiopicus* with *Eustrongylides* larvae have been recorded (Paperna, 1996). Additionally, Tadesse (2009) found *Eustrongylides* larvae in catfish at Lake Chamo, Ethiopia.



### **6.3 Missing parasite groups**

#### ***Ligula intestinalis* (Linnaeus, 1758)**

Britton et al. (2009) examined the occurrence of the parasite species *Ligula intestinalis* in Lake Baringo and Lake Naivasha. This tapeworm is very host-specific, only infecting species of the family Cyprinids. In Lake Baringo, *L. intestinalis* was recorded at a high prevalence rate in the species *Barbus lineomaculatus* (Britton et al., 2009). In the present survey, only one *Barbus* species, *B. intermedius australis*, was investigated for parasites, but yielded no findings of *Ligula intestinalis*.

#### **Acanthocephala (Kohlreuter, 1771)**

The absence of acanthocephalans in the parasite fauna of Lake Baringo is notable. These spiny-headed worms are present in many fish families. Moreover, this group is geographically widespread in Africa, recorded to be found in Kenya (Lake Victoria), Uganda (Lake Edward, George), Rwanda (Lake Kivu) and Tanzania (Lake Malawi) (Paperna, 1996). Definitive hosts for this parasite group are caimans or crocodiles (Aloo, 2002) and Lake Baringo has a large population of Nile crocodiles (*Crocodylus niloticus* (Laurenti, 1768)) (Britton et al., 2008). To conclude its life cycle, intermediate host arthropods (isopods, amphipods and ostracods) are required. Hickley et al. (2004) has stated that the lake's extreme turbidity and sediment accumulation is destroying the benthic fauna. Thus, the absence of *acanthocephalans* in Lake Baringo may be explained by these environmental changes leading to unacceptable habitat conditions for arthropods, the required first intermediate host.

#### 6.4 Diet and habitat composition of fish

The association between a fish's diet composition of fish and the appearance of parasites is an interesting and important factor for parasitological research. Depending on the food source of the host (algae, molluscs, fish, etc.) and life cycle of the parasite, different groups of parasites can be transmitted directly or indirectly through their hosts' food (Aloo, 2002; Dogiel et al. 1961). Fish can either be herbivores or carnivores, and either predatory or non-predatory. There are different patterns in the parasite fauna of fish depending on its food uptake. The diet of a fish is therefore a biotic factor that determines, in part, parasite species composition (Díaz & Muñoz, 2010). For example, omnivorous fish might have a higher species richness of trophically transmitted parasites (by food uptake) than those with a specialized diet (Cirtwill et al., 2015). The existence of transmitted parasites exposes trophic interactions among species and can shed light into their functions within an ecosystem (Díaz & Muñoz, 2010). Exceptions are free-transmitted ecto- and endoparasites that actively enter the host's body via the skin and are not influenced by the diet of their hosts (Dogiel et al., 1961).

Additionally, the habitat, and therefore the food resources, is another important aspect of parasite diversity and composition. For fish, the depth requirement of their habitat influences the infection rate of parasites. For example, shallow water fish, which are plankton feeders and mostly found in the pelagic zone, are prone to parasites that have zooplankton as an intermediate host, like in the case of nematodes and cestodes. Deep water fish are automatically excluded from high infection rates from these parasite groups, because zooplankton is not found in the deep water zone (Dogiel et al., 1961). Omondi et al. (2013) examined the feeding habits and diet composition of three fish species from Lake Baringo: *O. niloticus baringo*, *P. aethiopicus* and *C. gariepinus*, figure nine and table two. *O. niloticus baringoensis* is the only herbivorous fish species with zooplankton as part of its diet, though it feeds primarily on algae. Furthermore, zooplankton seems to be the first intermediate host for cestodes and is therefore responsible for the trophic transmission. A hypothesis for the extremely high infection rate is that during the dry season, the visibility of the water is better than usual due to the lower turbidity, enabling *O. niloticus baringoensis* to hunt for zooplankton more effectively and therefore a higher number of parasites can get accumulated (Omondi et al. 2013). Nevertheless, another, or perhaps, an additional assumption is that *O. niloticus baringoensis* is the only possible intermediate host, making the

cestoda species strict in its host-specificity, even though cestode larvae are normally considered as generalists (Paperna, 1996; Poulin, 2006). Even though, *O. niloticus baringoensis* has a narrower diet than *C. garipinus*, this does not mean, that the higher selection of food prevents fish from a considerable increase of parasites (Cirtwill et al., 2015).

The feeding habits for *B. intermedius australis* are adopted from the African Big Barb (*Labeobarbus intermedius*) of Lake Koka, Ethiopia to approximate their diet composition (Dadebo et al., 2013). This Barbel species is omnivorous; its diet includes insects, detritus and zooplankton. The prevalence rates of *Contracaecum sp.* are similar to those of *O. niloticus baringoensis*.

*C. garipinus*, also an omnivore but preferring benthopelagic vegetated marginal pools, mainly feeds on fish, zooplankton and detritus (Omondi et al, 2013). Their omnivorous behavior leads to a high number of possible first intermediate hosts. Food items such as fish and zooplankton are very likely to be intermediate hosts of a various number of helminths (Akoll et al., 2012). The presence of *Contracaecum sp.* is at its most frequent in this fish species, with an intensity of 8-49 parasites per fish. This can be explained by the large quantities of zooplankton they eat, especially for Copepoda, the first intermediate host of *Contracaecum sp.* (Paperna, 1996). Additionally, Paperna (1996) described how *Contracaecum sp.* occurs most in predatory fish, possibly explaining their low prevalence rates in *O. niloticus baringoensis*.

*P. aethiopicus* is an omnivore accepting a wide range of food but, in Lake Baringo, their diet is dominated by mollusks. This fish species is a benthicfeeder, groping the bottom of the lake in search of food (Omondi et al., 2013; Okeyo, 2003). Even though there is a low sample size of *P. aethiopicus*, there seems to be no trophic transmission of parasites through mollusks, fitting the explanation of Dogiel et al. (1961) that endoparasites actively penetrating the skin of a fish are not influenced by a fish's diet and habitat composition. For example, Clinostomatid metacercariae actively penetrate the skin of fish and do not infect *P. aethiopicus* via ingestion of their their intermediate hosts, mollusks. The transmission of *Contracaecum sp.* and *Eustrongylides sp.* could be explained by predation on other fish feeding on zooplankton (Paperna, 1996).

Differences between the species composition of parasites in various fish species are thus strongly linked with the fish's differences in diet and habitat composition (Akoll et

al., 2012; Dogiel et al., 1961). This means that the distribution and occurrence of the recorded parasites in Lake Baringo is often similar to other lakes in Kenya, Ethiopia, and Uganda, which are comparatively similar in the parameters of climate, altitude, abiotic factors, and biotic factors. But under natural conditions, a parasite fauna is never stable and varies over time. Environmental changes, as linked with changes in the ecosystem and habitat, greatly influences the intermediate and final hosts' biology, behavior and appearances, thereby producing variations in parasite richness and composition (Yimer & Enyew, 2003). As this is the first preliminary survey of the general fish parasite fauna of Lake Baringo, changes in the parasite fauna of Lake Baringo over time due to environmental alterations cannot be assessed here, but should be investigated in future studies.

## **6.5 Parasite abundance**

Host-parasite interactions are difficult to explain and likely to be unpredictable. Therefore, finding patterns to understand these relationships in a better way, is a general aim in parasite ecology. Especially recognizing distribution patterns of parasite abundance is a common goal, in regard to the epidemiological importance. Parasite abundance patterns are influenced by environmental variables and biological characteristics such as correlations between hosts body size and aggregation patterns among hosts distributions (Amarante et al., 2016; Poulin, 1999).

Due to the fact that resources are limited under normal conditions, a negative relation between the host's body length and parasite abundance can be observed. This is explained by limited resources and habitat possibilities in a certain area (Poulin 1999). The hypothesis for a positive relationship, which could be expected when resources are not limited, is based on an enlarged body volume and therefore on a higher availability for possible niches of parasite infections. However, this correlation is often not significant or even disproved and shows heterogeneous results. The inconsistency in this pattern could be indicated by changes in biotic habits of the host or by abiotic changes in the environment, which affect the trophic levels and species diversity (Amarante et al., 2016). In the conducted study, there is a weak and non-significant negative correlation of body size and parasite abundance of the two most common parasites, the cestoda larvae in the fish species *O. niloticus baringoensis* and *Contracaecum* sp. in *C. gariepinus*, see chapter 5.4. This weak negative correlation does not show unregulated pattern of host length in relation to host size, which of

course, influences the dispersion spectrum of parasites (Poulin, 1999). The dispersion of macroparasite individuals among the host population can be considered as a recurring and predictable natural phenomenon (Poulin, 2007). Poulin (2007) already defined this universal pattern as a general law in parasite ecology. Theoretically, three dispersion patterns are possible: underdispersed, random and overdispersed, or aggregated, distributions. Fish parasites are usually highly aggregated within their host population, showing overdispersion and a negative binomial distribution. This means that only a small number of hosts harbor nearly all of the parasites found; in other words, there are very high infection rates (Pennycuik, 1971). This variability is caused by heterogeneity in the host's behavior and immunity, environmental elements, and in the spatial distributions of the parasite's development stages. Some species also adopt strategies to reproduce directly in their hosts (Anderson, 1993). In the current study, the two most prevalent parasite species *Contracaecum sp.* in *C. gariepinus* and the unidentified cestoda larvae in *O. niloticus baringoensis* also follow this aggregated pattern, see chapter 5.4. Underdispersed distributions rarely occur and may be due to unusual or dynamic natural events. This theory implies there is a lower possibility of infection when the environment of a host changes due to an interrupted host biology with altered food and habitat selection (Esch & Fernandez, 1993). Still, parasite mortality, homogeneity of host population and host mortality due to parasite infection explain underdispersed distributions (Anderson, 1993). In Lake Baringo, there are dramatic changes in the environment going on influencing the organisms living in the lake (Omondi, et al., 2014). Still, the results of this study do not show any unusual variance in the distribution patterns of the parasites. Thus, we confirmed the general assumption that parasites are always found in clustered aggregations within their host populations.

## **6.6 Human Risk Potential**

Large numbers of parasites have been recorded in freshwater and marine fish. Nevertheless, only a few parasites, roughly 50 worldwide, are capable of infecting humans (Adams et al., 1997). And though most cause almost no harm, there are still species that pose a serious risk to human health (Lorber, 2006). The following helminths are considered the most dangerous species: anisakid nematodes, cestodes (genus *Diphyllobothrium*) and digenetic trematodes (families *Heterophyidae*, *Ophistorchidae* and *Nanophyetidae*). However, infection is only possible when fish are

prepared in traditional ways: partially cooked, smoked or raw (Adams et al., 1997). Especially the two species *C. multipapillatum* and *C. micropapillatum* often appear in African fish, but only *C. multipapillatum* was found to cause infections on *O. niloticus* (Florio et al., 2009). In particular, the larvae of *Contracaecum multipapillatum* is potentially zoonotic (Florio et al., 2009).

### **Cestodes**

Diphyllobothriosis is the most dangerous fish-born zoonosis and is caused by a cestoda parasite infection (genus *Diphyllobothrium*) (Adams et al., 1997). Though Scholz et al. (2009) stated that this tapeworm species is not found in Africa, *Diphyllobothrium latum* was found in *C. gariepinus* in Maiduguri, Nigeria (Biu & Akorede, 2013), rejecting this previously made statement. Nevertheless, the unidentified cestoda larvae were only found in the gut wall of *O. niloticus baringoensis* and these body parts of the fish are removed when cleaning the fish, lowering the risk of infection.

### **Nematodes**

In this survey, *Contracaecum sp.* was investigated free living in the body cavity or encapseld in three fish species, *O. niloticus baringoensis*, *B. intermedius australis* and *C. gariepinus*, and found to have moderate to high infection rates. Species of this anisakid genus (*Anisakis*, *Pseudoterranova* and *Contracaecum*) are known to be zoonotic and cause serious diseases (Florio et al., 2009). This zoonotic infection, called “anisakiasis” is transmitted through the third larval stage of this nematoda. If the parasite is accidentally transmitted to humans due to fish not being cooked thoroughly, it can migrate to the gastrointestinal tract, peritoneal cavity and various organs (Adams et al., 1997). The clinical symptoms of this illness are stomach pain, diarrhea, vomiting and fever. In addition, some people exposed to fish products through their work have had allergic reactions to anisakid allergens (Berger, 2010; Shigut & Arefainie, 2014). Furthermore, the nematode *Eustrongylides sp.*, which can be also accidentally transmitted to humans, was found sporadically, but encysted in two fish species, *O. niloticus baringoensis* and *P. aethiopicus*. Human parasite infections with the larvae *Eustrongylides sp.* are rare, but this nematode has been found in the peritoneal cavity of humans. In these cases, the parasite has to be taken out by surgery (Moravec, 1998). The larvae of *Eustrongylides sp.* is normally easily visible, red and up to ten cm

long but it can be found encysted in the musculature of fish, white and only one cm long, and therefore easily be eaten by mistake (Hoffman, 1976).

### **Digenean trematodes**

Even though parasites of the genus *Clinostomum* are common worldwide, there exist occasional cases where digenean metacercariae of *Clinostomum complanatum* has been found to infect human organs following consumption of infected food, representing a limited public health risk (Aohagi et al, 1992; Chung et al., 1995; Park et al., 2009). *Clinostomum* infections are more often reported in Japan and other countries, where fish is prepared raw more often. Nevertheless, *C. complanatum* occurs across Africa within several fish species (Paperna, 1996). Chung et al. (1995) found that all species of the genus *Clinostomum* are either synonyms of *C. complanatum* or misinterpretations of other genera. In its final host, piscivorous water birds, this parasite species colonizes the throat and esophagus (Chung et al., 1995). In humans, the symptom is a strong pain in the pharyngeal region when the parasites settle at the mucous membrane in the throat. When this happens, the parasite has to be removed (Park et al., 2009).

## 7 Conclusion

This is the first survey regarding the diversity and distribution of fish parasite species in Lake Baringo. We examined the four commercially important fish species, *O. niloticus baringoensis*, *P. aethiopicus*, *G. gariepinus* and *B. intermedius australis* for ecto- and endoparasites. Nevertheless, this research was focused on helminths, the systematic groups of digenean trematodes, cestodes, nematodes and acanthocephalans, with ten parasite groups recorded. Species of the systematic classes Cnidosporidiae, Monogenea and Crustacea are considered to be autogenic ectoparasites. Concerning the endoparasitic helminths, seven parasite groups belonging to the classes Trematoda, Cestoda and Nematoda were found. The systematic group Acanthocephala was completely absent, possibly due to its first intermediate host's habitat conditions being unacceptable. Eight recorded species were considered as generalists and, of them, seven metazoan parasites have piscivorous water birds as possible final hosts. Lake Baringo offers an extraordinarily high biodiversity of birds, making available a high number of possible definitive hosts. Based on these findings, the first Hypothesis "*Fish of Lake Baringo are not infected with parasites*" can be rejected.

The fish species *O. niloticus baringoensis* was dominated by Cestoda, in all other fish species the most abundant group was Nematoda. The nematode species *Contracaecum sp.* infected all four fish species, the highest prevalence of 100% present in *C. gariepinus*. The two most frequent parasites, unidentified cestoda larvae in *O. niloticus baringoensis* and *Contracaecum sp.* in *C. gariepinus* follow common dispersion patterns and are aggregated within their host populations. Regarding the component community level, the parasite community richness was highest for *O. niloticus baringoensis* with seven taxa followed by *C. gariepinus*. *P. aethiopicus*, which has been deficient in detailed scientific information, showed very low infection rates of only two nematode species: *Contracaecum sp.* and *Eustrongylides sp.*

The results of these analyses reject the second hypothesis "*There is no difference in the prevalence, mean intensity, abundance and species composition of parasites in the four fish species O. niloticus baringoensis, B. intermedius, C. gariepinus and P. aethiopicus*".

Similar results were found in other East African lakes when the species richness and distribution of fish parasites was compared. Three species were recorded to be



potential risks to human health: digenean metacercariae of the genus *Clinostomum* sp. and larval nematodes of the genus *Contraecum* sp. and *Eustrongylides* sp.

## 8 Recommendations

This is the first survey of fish parasite fauna that addresses more than one fish species in Lake Baringo. Because of the ongoing environmental changes in the catchment of Lake Baringo, effects on parasite populations are highly possible. To approach these environmental forces and the natural dynamics of the parasite fauna, long-term and lake-wide assessments of parasites and their possible intermediate and final hosts are recommended. These investigations would also help to expand our knowledge of parasite ecology and help to understand phenomena like the seasonal occurrence of fish parasites. Studies on parasite biology and ecology would support the development of a countrywide monitoring system, providing better control and preventative measures against parasitic disease in fish. Moreover, ectoparasitological investigation should be performed as well as bacterial or viral studies should be taken into considerations.

In Lake Baringo, the digenean metacercariae of the genus *Clinostomum* sp. and larval nematodes of the genus *Contracaecum* sp. and *Eustrongylides* sp. were recorded and represent possible risks to human health, as these species can accidentally infect humans. The local community should be provided with health education containing information about transmission risks associated with eating raw, partially cooked, or smoked fish, and be informed of the safest ways to prepare fish. Furthermore, case studies on the health of the local people are recommended to assess the appearance and effects of these parasites in humans.

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